FOOD OF CROPS

BY C. M. AIKMAN

THE

FOOD OF CROPS

AND

HOW TO APPLY IT.

(*An Elementary Handbook on the Science and Practice of Manuring.*)

BY

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PREFACE.

THIS little work is intended as a guide to the elementary principles involved in the application of fertilisers. It does not in any sense claim to be a treatise on the subject of manures; and may be regarded as forming an introductory text-book to the author's manual on "Manures and Manuring" (Blackwood). It is hoped that the elementary facts of agricultural chemistry, necessary for an intelligent comprehension of the subject, are stated in such a way that readers unacquainted with natural science will have no difficulty in mastering them.

In the hope that the book may prove itself to be suitable for use in rural schools, where agricultural science is taught, a number of questions have been added as an Appendix.

It is surely unnecessary at the present time to say a single word on the enormous economic importance of the subject treated. The use of fertilisers has become a necessity of modern husbandry, and the amount of money yearly spent on them in this country alone amounts to millions sterling. Any book, therefore, which helps, in however humble a way, to diffuse a knowledge of the correct principles underlying this practice may claim to have a *raison d'être.*

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CONTENTS.

CHAPTER I.

SOURCES OF PLANT FOOD.

CHAPTER II.

HOW PLANTS FEED.

CHAPTER III.

THE NATURE AND FUNCTIONS OF FERTILISERS.

CHAPTER IV.

FARMYARD MANURE AND SEWAGE.

CHAPTER V.

GUANO.

CHAPTER VI.

NITRATE OF SODA, SULPHATE OF AMMONIA, AND OTHER NITROGENOUS FERTILISERS.

CHAPTER VII.

BONES.

CHAPTER VIII.

SUPERPHOSPHATE AND MINERAL PHOSPHATES.

CHAPTER IX.

POTASH FERTILISERS.

CHAPTER X.

INDIRECT MANURES.

CHAPTER XI.

THE COMPOSITION AND APPLICATION OF FERTILISERS.

CHAPTER XII.

THE MANURING OF THE COMMON FARM CROPS.

THE FOOD OF CROPS

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CHAPTER I.

SOURCES OF PLANT FOOD.

THE phenomenon of plant growth is one of the most interesting of the many striking phenomena which nature presents for our observation. What further serves to invest it with interest is the fact that it is one of enormous economic importance, for on it the great industry of agriculture rests.

The questions—What is the food of plants? and Whence do they derive this food? were doubtless asked by many searchers after truth in the past; but were destined long to remain unanswered.

If we take any piece of vegetable tissue, whether it belong to the root, stem, or leaf of a plant, and submit it to chemical analysis, we shall, by this means, discover its composition.

In the first place, if we take and heat it for some time at the temperature of boiling water, we drive off what is its largest constituent—viz., *water*. This amounts, in many plants, to over 90 per cent. of their total weight,

and is rarely less than 40 per cent. The plants which contain most water are succulent vegetables—such as lettuce, gourds, melons, &c. These, indeed, are almost entirely made up of water—some of them containing as much as 97 per cent. Such plants as turnips contain over 90 per cent., mangolds slightly less, while potatoes contain about 75 per cent. On the other hand, timber, when felled, contains only about 40 per cent. In the grains and seeds of plants we find the percentage of water very much less, being only about 14 per cent. The amount of water in plant tissue depends on the period of growth. It is greatest in young plants, and as the plant grows older it decreases.

By proceeding a step further, and submitting the dried plant tissue to a higher temperature, we find that it speedily blackens, while smoke is given off. This blackening indicates to the eye of the chemist the presence of the element *carbon*. If we steadily raise the temperature to a red heat, the carbon gradually disappears, until all that remains, after a time, of the plant substance is a small amount of ash.

The dry matter of plants can thus be divided into two portions—one *which we can burn away*, and which is by far the larger portion; and one which *withstands the action of heat*. This combustible portion is generally called the *organic matter*, while to the incombustible portion the terms *inorganic* or *mineral matter* have been applied.

The relative proportion of the organic and inorganic parts of plants varies, and the different parts of even the same plant show a variation in composition. Thus, as a rule, the leaves will be found to contain more ash than the stem or roots. So great, indeed, is this varia-

tion that it would be misleading to give any amount as furnishing an average. Almost never, however, does the ash in a plant, or in any part of a plant, exceed 20 per cent. of its dry matter; while in certain cases it may not exceed the mere fraction of a per cent. In the common agricultural plants, the grain, or seed, may be said to contain 2 to 3 per cent. of ash, and the straw about 5 per cent. The organic matter in these parts of the plant will thus vary between 95 and 98 per cent.

If we examine more minutely these two portions of the plant tissue—the organic and inorganic matter—with a view to discovering their chemical composition, we shall find that the organic matter is made up chiefly of *carbon*. That this is so we can prove by collecting the gaseous products of combustion, when it will be found that the largest percentage consists of carbonic acid gas, a substance formed out of carbon and oxygen, and produced whenever carbon is burned in the air. Broadly speaking, this may be said to amount to close on 50 per cent., or one-half of the entire amount of the dry substance of the plant. Next in amount to carbon comes *oxygen*, which is present in quantities only a little less than the carbon, viz., about 40 per cent. The remaining portion is chiefly made up of *hydrogen and nitrogen*, the latter substance being present to the extent of only 1 or 2 per cent., while the former amounts to about 6 per cent. The presence of hydrogen in the organic matter of plants is shown by the fact that when *dry* plant tissue is burned in air a certain quantity of water is formed.

These four elements, which, along with small quantities of sulphur, constitute the organic matter of the plant, are

combined together in different proportions to form a large variety of bodies. Most of them are made up of only the three elements—carbon, hydrogen, and oxygen. To one large class of such bodies the name *carbohydrates* is given. *Cellulose*, or woody fibre (the most abundant substance in plant tissue), *starch*, and *sugar* may be cited as examples of this class of substances. Other bodies, made up of the same three elements, are *fats*.

But a certain proportion of plant tissue consists of bodies which, in addition to carbon, hydrogen, and oxygen, also contain nitrogen. These are known as *proteids* or *albuminous* bod es. *Gluten*, that glue-like substance familiar to most as an important constituent of wheat, may be taken as a type of this class of body.

Turning, in the second place, to the ash, we find that the elements constituting this portion of the plant tissue are more numerous than those forming the organic part. Among them may be mentioned *potassium*, *calcium*, *magnesium*, *sodium*, *silicon*, *iron*, *and phosphorus*. These elements are combined with oxygen, and are present in the form of a number of different kinds of *salts*.

We see, therefore, that plant tissue is made up of *water*, *organic matter* (consisting of compounds of carbon, hydrogen, oxygen, and nitrogen), and of certain *mineral* or *ash ingredients*.

The next question which we have to consider is—Whence does the plant derive these substances? Now, there can be only two sources, viz.: the *air* and the *soil*. An examination of the composition of the air will reveal that it is chiefly made up of two gases, *nitrogen* and *oxygen*, but that it also contains comparatively small quantities of *carbonic acid gas*, as well as *water* (in a state

of vapour), and certain other gases in, however, very minute quantities; while an examination of the soil will show that it contains, in addition to varying quantities of organic matter, all the mineral constituents which we find to be present in the plant. We see, then, that the source of certain constituents of the plant must be the soil, since these ingredients are not present in the air. This is the case with regard to the ash or mineral portion. With regard to the others, however, the matter is not so quickly decided. Thus, with regard to carbon, for example, we find that this substance is present in a combined form —*i.e.*, in chemical combination with some other substance —both in the soil and in the air. Again, oxygen is abundantly present in a combined form in the soil as well as in the free state in the air. Hydrogen, further, is present in a combined form, both in the air and in the soil. While, lastly, nitrogen is present in both the air and the soil—in the former, both in the free state and, in very minute quantities, in the combined form; and in the latter, only in the combined form. The question, therefore, arises, From which of these sources, respectively, does the plant derive these elements?

With regard to carbon, hydrogen, and oxygen, we know that while the first named is obtained by the plant from the small quantity of *carbonic acid gas* present in the air, the source of the hydrogen and oxygen is *water*. With regard to nitrogen, however, we find that the plant draws on both the soil and the atmosphere for its supply of this important element, although, to most plants, the soil furnishes the only source. The discovery that so-called leguminous plants—a large and important class, including the pea, bean, and clover crops—are capable of deriving their nitrogen from the

free nitrogen in the air, has only been made within recent years, and may be rightly regarded as one of the most important discoveries made in agricultural science for a long time.

We thus see that the plant derives by far the larger portion of its substance from the air and water, and that only a small portion is derived from the soil. And here an interesting question presents itself, viz., Are all the ingredients commonly found in plants absolutely necessary for the plant's proper development? To this an answer in the negative must be made. Most of the substances we have mentioned, which go to form plant tissue, are absolutely necessary, and among these are all the elements which go to form its organic matter. But among the ingredients forming the inorganic or ash portion there are one or two which, although they commonly occur in most plants, are yet not absolutely necessary for plant-growth, and without which the plant can make shift to grow perfectly well.

It would seem at first sight, therefore, that the influence which the farmer can exert on the growth of his crops must necessarily be very small, since by far the largest portion of the substance of these crops is derived from a source not under his control. When, however, we come to examine the problem of plant growth more nearly, this will be seen to be a mistaken conclusion. For, while such ingredients as *phosphoric acid* and *potash* are only required by a plant to a comparatively small extent, yet both these substances are as necessary for its growth as carbonic acid gas or water—food ingredients out of which plant tissue is so largely built up.

All the *necessary* plant foods, therefore, may be re-

garded, as far as the growth of a plant is concerned, as of equal importance. It thus happens that although the farmer is only able to control the source of supply of a very small portion of the plant's food, he is yet able to regulate, to a large extent, its growth.

And here it may be well to point out that plant growth is not alone determined by the amount of plant food available, but that such conditions as *climate*, *altitude*, *physical texture* of the soil, &c., are also quite as potent factors. As, however, we are not here concerned with anything but the food of plants, it will be unnecessary to consider the extent or nature of these other influencing conditions of plant growth.

CHAPTER II.

HOW PLANTS FEED.

WHEN the seed is put into the ground, provided the conditions of warmth and moisture are favourable, it soon begins to sprout. A shoot is pushed upwards, and a root downwards. Now, during this period of *germination*, as it is called, the external sources of the plant's food, the soil and the air, are not drawn upon, except in so far as one ingredient is concerned, viz., water. The seed itself supplies, for some little time, all the food necessary, there being in it a sufficient amount of concentrated nourishment to permit of the plant's growth, until it is able, by means of its leaves and roots, to draw its nourishment from external sources. With the exact nature of the changes which go on in the seed during this important stage of the plant's life we need not here concern ourselves. It may be sufficient to mention that the seed contains a certain proportion of carbohydrates in the form of starch, nitrogenous bodies of the nature of gluten, and mineral matter. In some seeds, it is true, we have no starch—its place being taken by oil.

When germination takes place the starch is converted, by means of a ferment called *diastase*, into soluble bodies which are able to travel in the sap to the shoot or root, and thus to permit of the development

of these organs. If this initial stage of growth is to take place satisfactorily, a proper amount of moisture, a certain temperature, and a free supply of air are all required. It is for this reason that seeds, if buried too deep, where the air does not penetrate, refuse to germinate. As soon, then, as the plant's roots and stem have developed so far as to permit of it drawing upon the soil and the air for its food, it does so.

As we have pointed out, the carbon, which forms the largest portion of plant tissue, is derived from the carbonic acid in the air. Under the influence of sunlight this gas is decomposed in the green portion of the leaves of the plant into *carbon* and *oxygen*, the carbon being retained, and the oxygen given out. This process of *carbon assimilation*, as it is called, only takes place in the day time, since sunlight is necessary for its action, and the rapidity with which it goes on depends on the intensity of the sun's rays. This accounts for the fact that during periods of the year when the sun's rays are most powerful, and daylight is longest, plant growth is greatest.

But an interesting question may occur to the reader, viz., how can such a minute quantity of carbonic acid as that present in the air (amounting to only some three to four parts per 10,000) supply plants with the large amount of carbon they require, for it has been calculated that an acre of a good wheat crop will assimilate in four months as much as one ton of this element; and this is as much as would be contained in a column of air covering an acre of ground, and stretching to a height of three miles. We must remember, however, that although the quantity of carbonic acid gas in the air is very small,

and the surface that the plant leaves offer to the atmosphere is also comparatively small, the air surrounding a plant is constantly undergoing change. This constant shifting of the atmosphere around the plant is, of course, effected by the wind, and, as an example of the rapidity with which it takes place, it may be mentioned that even on the least windy day, when the wind is only moving at the rate of two miles an hour—and this is so slow as scarcely to be noticeable—the air in a space of twenty feet is changed more than 500 times in an hour.

And here we may explain how the carbonic acid gas, which is such an important plant food, and which is thus constantly being removed from the air, is supplied. In the first place, we have large quantities formed from the decay of vegetable matter. This process of putrefaction of organic matter is constantly going on in all soils, and in illustration of its extent it may be mentioned that it has been calculated that one acre of good garden land in summer evolves more than six tons of carbonic acid. Another large source is the combustion of organic matter, which is especially great in the neighbourhood of large towns. To the respiration of man and animals the air also owes a not inconsiderable proportion of its supply of this valuable plant-food. While, lastly, in the gases from volcanoes, from mineral springs, and from various other subterranean sources, the air is constantly receiving carbonic acid gas.

Since the carbonic acid is a product of the respiration of animals, the influence of plant life on our atmosphere is towards purifying it of this noxious (to animal life) ingredient; and the counteracting influence of animal and vegetable life is illustrated by the calculation that

an acre of forest will decompose the carbonic acid produced by the respiration of fifteen men.*

In view of the importance of carbonic acid as a plant food, it may naturally be asked whether plants flourish better in an atmosphere containing a larger proportion of carbonic acid than that present in the air. It has been found by experiment that plants flourish better when the proportion of carbonic acid in the air surrounding them is increased. This takes place, however, only up to a certain point, viz., 8 to 10 per cent. of carbonic acid; and when air contains more than that amount it is no longer suitable for supporting plant life.

The decomposition of carbonic acid by the leaves of plants is intimately connected with the green colouring matter called *chlorophyl.* What exact functions chlorophyl performs is not fully known; but examination by the microscope has shown that carbonic acid is only decomposed in those portions of the plant which contain chlorophyl. To this there must be an exception made, since it has been recently ascertained that in the case of very minute low forms of plant life (certain soil organisms) neither light nor the presence of chlorophyl are necessary conditions for the assimilation of carbon and the evolution of oxygen.

With regard to the absorption of oxygen and hydrogen, we know very little beyond the fact that these two substances are probably almost entirely obtained from water. Oxygen, it would seem, is not derived from the free oxygen in the atmosphere, although that doubtless

* The sources of supply seem pretty nearly to equal the demands made on them by the plant world, and the amount in the air thus remains approximately constant.

plays an important part in the growth of plants, and a free supply of it is necessary for their development.

With regard to the assimilation of nitrogen, the question is not so shortly or so simply disposed of. The amount of this element in plants is not less than 2 per cent. Now, as four-fifths of the volume of the air consists of this element, one would naturally suppose that from this source plants would derive all their nitrogen ; and it is true, for a certain class of plants, that they do draw upon this source. But most plants derive their nitrogen from the compounds of that body in the soil. This substance occurs in the soil in the form of what is termed *organic nitrogen*, that is, as albuminoids and other analogous forms, as well as in the form of *nitrates*, *nitrites*, and *ammonia*. The first-mentioned form (organic nitrogen) is the most abundant, and nitrogen is only gradually converted from this form by various processes, in which minute organisms play a very important part, into the other forms we have just mentioned. This is an important fact, since, in the form of nitrates, nitrogen is apt to be washed out of the soil. In the form of ammonia it is more tenaciously held, but it does not long remain in this state, being speedily converted into nitrates.

Of these different forms of nitrogen, that in the form of nitrates is the most valuable for the plant, since it is in this form that plants absorb nearly the whole of the nitrogen they require. For the reasons above mentioned, nitrogen in the form of ammonia may be described as of almost equal value. With regard to the value of nitrogen in the organic form, it is impossible to speak generally, since this depends very much on the nature of the special organic compound. We have organic forms

of nitrogen, such as *urea*, the form in which it is present in fresh urine, which, from the fact that when they are applied to the soil they are rapidly converted into nitrates, are almost as valuable as nitrates themselves. On the other hand, nitrogen in the form in which it occurs in bones is of very inferior value, since such nitrogen is only very slowly converted into nitrates.

As the processes by which the various forms of nitrogen are converted into nitrates in the soil have a very important bearing on their value as plant food, it may be well here to shortly describe them, as well as to say a word or two on the method in which certain plants are enabled to draw their nitrogen from the free nitrogen in the air.

The conversion of nitrogen in the organic form, and in the form of ammonia salts, into nitrates is effected by different minute organisms which inhabit the soil, and which have only of recent years been discovered and investigated. In the conversion of ammonia into nitrates two classes of organisms are active. The ammonia is first converted into nitrites by one class of organisms, and the nitrites are converted into nitrates by another class of organisms. Where the nitrogen is in an organic form, the process is more complicated, as it has first to be converted into ammonia by a third class of organisms. Now, the conditions which favour the development of these processes, which are known under the term *ammonification* and *nitrification*, are, from an agricultural point of view, of the very highest importance, since, in the cultivation of his land, the farmer should aim at developing them to the greatest possible extent.

In the first place, the nitrification organisms require,

just like the higher plants, a certain amount of food constituents, a free supply of air, and a certain amount of moisture. Another important influencing condition is the temperature. Experiments have shown that they will only develop between 40° Fahr., and 131° Fahr.; and that a temperature slightly less than 140° Fahr. is the most favourable. Soils where any of these conditions are wanting are, therefore, not likely to prove themselves fertile.

While it has long been suspected that the free nitrogen in the air is available as a source of plant food, it is only within the last few years that this fact has been demonstrated beyond doubt. So far as is at present known, the power of utilising the free nitrogen of the air is limited to a certain class of plants, viz., those known as *leguminous* plants, and examples of which are clover, beans, peas, &c. The method in which these plants can utilise this free nitrogen is still a point requiring much research. The *fixation* of the nitrogen, as it is called, is effected by means of micro-organisms present in certain minute *root-excrescences* found on the roots of these plants.

In addition to the nitrogen which is absorbed by leguminous plants, the air supplies minute quantities of it to the soil in a combined form. This combined nitrogen is in the form of ammonia and nitrates, which exist in minute traces in the air, and are washed down by the rain. The amount obtained in this way, however, is very trifling. Thus, at Rothamsted, in England, that falling on an acre of land, in the rain, was only some 3·37 lbs. during a year. It is possible that, in addition to this, minute quantities of ammonia may be absorbed by the soil from the air. The large bulk of the

nitrogen which the plant requires is obtained from the soil. Hence the amount of nitrogen in the soil is one of the regulating factors of plant growth. With regard to the ash constituents of plants, we have seen that all those commonly occurring in plants are not of equal importance, and that only some of them are absolutely necessary for plant growth. Those that are necessary are as follows: *potash*, *lime*, *magnesia*, *oxide of iron*, *phosphoric acid*, and *sulphuric acid*. Some of these are only required in very minute quantities, this being the case with regard to oxide of iron. Of them, two possess for us especial importance, viz., *potash* and *phosphoric acid*. This is due to the fact that they are generally present in the soil, in an available condition at any rate, in *very small amount*; whereas the other necessary ingredients are contained by most soils in abundant quantity. As we have already had occasion to point out, *the rate of growth of a plant is determined by the amount of the least abundant necessary available plant constituent in the soil*. Thus, for example, crops will not properly grow in the absence of any one necessary plant constituent, no matter how abundant the other necessary plant constituents are. It is, therefore, the constituent which is relatively least abundant that regulates the rate of growth. As these two constituents, among mineral constituents, are potash and phosphoric acid, they possess, for the farmer, the greatest interest, and are the only two which, as a rule, it is found necessary to apply as manures. Under ordinary agricultural conditions, therefore, the question of manuring may be said to be limited to the addition to the soil of *nitrogen*, *phosphoric acid*, and *potash*. We have already seen the forms in which nitrogen is present in the soil and is absorbed by

plants. Before concluding this chapter, let us see in what forms these two mineral ingredients are present in the soil, and are absorbed by plants.

The number of different chemical compounds of phosphoric acid in the soil are not so numerous as those of nitrogen. Unlike this latter ingredient, it is probably never present in a soluble form,* and when added to the soil in this state it is speedily converted into an insoluble condition. This is a fortunate circumstance, since it is not liable to be lost by being washed out of the soil by rain. But the readiness with which the different compounds of phosphoric acid are acted upon by the plant's roots, and by soil water, varies very considerably. Many compounds of phosphoric acid, although insoluble in pure water, are yet acted upon more or less easily by soil water charged with carbonic acid.

Perhaps the most insoluble form of phosphoric acid in the soil is *apatite*—a crystalline mineral which consists almost entirely of phosphate of lime. This mineral is only very slowly decomposed, and yields its phosphoric acid to the plant only after a long period of decomposition. The other compounds of phosphoric acid in the soil are phosphates of iron and aluminium, and, possibly, also phosphates of magnesium and ammonium. But among the phosphates of lime great difference exists in their assimilability by the plant's roots. Thus phosphates derived from animal or vegetable matter become more speedily available in the soil for the plant's needs than mineral phosphates such as apatite. The fertility of a soil may be said to depend more on the amount of speedily available plant food than on the

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* By *soluble* and *insoluble* is meant soluble and insoluble in *water*.

total amount of this plant food. Very many methods have consequently been suggested for the purpose of attempting to gauge this amount of available mineral plant food. That recommended by Dyer consists in the treatment of the soil with a 1 per cent. solution of citric acid. The amount of phosphoric acid dissolved by such a solution from most soils would probably be very little.

Potash is a more abundant ingredient in most soils than phosphoric acid; yet the amount present, in a form available for the plant's needs, is also comparatively small. The form in which it most commonly occurs is as the mineral *felspar*. This mineral, which may contain it to the extent of 14 per cent., is extremely hard, and is only very slowly decomposed. The potash in it is in combination with silica—that is, in a totally insoluble form. Through the process of "weathering" the potash in this mineral is slowly set free, and rendered available for the plant's uses. Another common potash mineral is *mica*—so large a constituent of granite.

The form in which potash is probably absorbed by plants' roots is in combination with chlorine, sulphuric acid, or phosphoric acid, all three forms being soluble. It is more liable to be washed from the soil by rain than phosphoric acid, although loss of it from this source does not occur to anything like the extent which one would be inclined to suppose, since the soil has the power of retaining it and certain other plant foods, although in a soluble condition, against the action of rain—an extremely economical provision of nature.

CHAPTER III.

THE NATURE AND FUNCTIONS OF FERTILISERS.

In a state of nature, where plants decay where they grow, the mineral and nitrogenous food which they extract from the soil is returned to it, and the soil, instead of becoming impoverished in food constituents, is found, on the contrary, to slowly become enriched. When this process continues for centuries, the result is the formation of soils of wonderful fertility, of the type of the old "virgin soils"—now becoming so rapidly extinct—in America. This enrichment is due to the fact that the soil has had concentrated on its surface layers large quantities of readily available food ingredients, gathered by the plants' roots from its lower portions, as well as accumulated from the air by the fixation of free nitrogen.

In agricultural practice, however, where such a process of accumulation is not allowed to take place, the case is very different. As is well known, the tendency in such a case is towards a diminution in the fertility of the soil, due to a steady loss of plant food. This takes place in a variety of ways. In the first place, large quantities of plant food are removed from the soil by the crops which are not consumed on the farm. The extent to which the different important plant foods are removed by the common agricultural crops is as follows: Average crops of cereals (oats, wheat, and barley) remove about 50lbs. of nitrogen, 20 lbs. of phosphoric acid, and about 40 lbs. of

potash per acre. A certain proportion of this, however, is almost invariably returned in the straw, which contains about 15 lbs. of nitrogen, 5 lbs. of phosphoric acid, and about 30 lbs. of potash. An average crop of turnips removes even larger quantities of these constituents, viz., about 119 lbs. of nitrogen, 33 lbs. of phosphoric acid, and 139 lbs of potash per acre; while an average crop of mangolds removes 138 lbs. of nitrogen, 53 lbs. of phosphoric acid, and 300 lbs. of potash per acre.

A more striking way of indicating the amount of fertilising constituents removed from the soil in this way is to calculate what the total produce of a year's growth represents in these ingredients. The present writer had occasion some years ago to calculate the amount of nitrogen removed by the three cereal crops, wheat, barley, and oats, from the soil of Great Britain in a single year. This was found to amount to over 120,000 tons, to replace which it would require over half a million tons of *sulphate of ammonia*, or more than three-quarters of a million tons of *nitrate of soda* —the two most abundant and valuable of our artificial nitrogenous manures.

Of course, it must be remembered that all this is not removed from the farm. Much of it finds its way back again to the soil in an indirect manner. And this leads us to say a word or two on the chief method in which this is effected, viz., by the application of farmyard manure.

Farmyard manure is made up of straw and the excreta of farm animals. Its chief value is due to the nitrogen which it contains in a soluble form, derived from the urine. It also contains a certain

quantity of phosphoric acid and potash in a soluble form. Now, in keeping for some time, farmyard manure is apt to lose much of these soluble plant foods, which are apt to be washed out of it by the rain. Much of this loss can be easily prevented when the manure is properly kept. Unfortunately, however, there has been in the past, and there still is, an enormous loss annually taking place in different farms throughout the country in this way. Taking only into account the nitrogen, this loss has been reckoned at about 40,000 to 50,000 tons, equal to as much nitrogen as is contained in from 240,000 to 300,000 tons of nitrate of soda. If we take the value of this substance at £10 a ton, some conception of the loss is afforded. Grandeau, an eminent French authority, calculates that the value of the farmyard manure produced in France is initially worth £66,000,000 a year, and that about a sixth of its value is lost by careless management.

Again, the system of thorough drainage—which is so characteristic of modern agriculture—has much increased the loss of fertilising constituents. It is impossible, of course, to estimate what this loss amounts to, because so much depends on a variety of conditions. It has been found at Rothamsted that, under circumstances most favourable to extreme loss—that is, on unmanured fallow land—as much as 54 lbs. of nitrogen per acre was lost by drainage in the course of a year; that is to say, as much nitrogen as is contained in 2 cwts. of nitrate of soda. This, of course, is under the most unfavourable circumstances. The average loss per acre is probably far below this, and has been estimated by a well-known authority at not more than 8 lbs. per annum per acre for this country.

The loss of phosphoric acid and potash, although very much less, is still considerable, as is evidenced by the statement that the river Elbe has been found to carry out to sea, yearly, more than 1,200 tons of phosphoric acid; and more than 43,000 tons of potash, which have been derived from the drainage water of the fields of Bohemia.

It is true that in nature we have certain processes going on which help, to a certain extent, to neutralise this loss. Such processes are the fixation of free nitrogen from the air by certain plants—already referred to—as well as the slight quantity of combined nitrogen washed down in the rain. It is found, however, in actual practice that such sources of gain are generally entirely inadequate to make good the loss constantly going on. The above considerations show, therefore, the necessity for the application of artificial fertilisers.

But while it is comparatively easy to see the strong reasons there exist for applying artificial manures, the art of their economical application is far from easy; in fact, it may be fairly regarded as one of the most difficult problems which the farmer has to face. Their expensive nature, and the great risk they run of being lost through injudicious application, are two points which contribute to this difficulty. The fact that plants differ very considerably in the capacity they possess for utilising the different food materials in the soil is a further consideration which has to be taken into account in the application of fertilisers. Altogether the subject is fraught with great difficulty. Before dealing with the manuring of the different common farm crops, it will be advisable to give a short description of the chief fertilisers in use.

In the first place, it may be advisable to say a word or two on the classification of the different fertilisers. We have already mentioned that the only plant food ingredients which are, as a rule, applied as fertilisers are nitrogen, phosphoric acid, and potash. The commercial value of a manure is, therefore, dependent on the amount, as well as the chemical form, in which any of these substances is present in it; and when manures are analysed under the Fertilisers and Feeding Stuffs Act only the percentage of these three substances is stated. It is well that all who have to deal with fertilisers should clearly understand this.

If we define a fertiliser, however, to be a substance which when added to the soil increases its fertility, and thus enables plants to grow in it more luxuriantly, we must include under the definition of fertiliser certain substances which, although they do not contain any of the above-mentioned plant foods, yet when applied to soil exercise an influence on its fertility. This they effect in an indirect manner; some by improving the soil texture, and thus influencing certain physical or mechanical properties which have a bearing on its fertility, and others by acting upon the dormant or reserve plant-food in the soil and converting it into a condition in which it is available for the immediate needs of plants. Such substances are generally known as indirect fertilisers. Of these the chief are compounds of lime such as *burnt lime*, *mild lime*, *gypsum*, *common salt*, &c.

Fertilisers may thus be divided into two great classes: first, those containing *nitrogen*, *phosphoric acid*, and *potash*, and which contribute directly to the fertility of the soil—such substances being known as *direct* manures

(more commonly known simply as manures); and, secondly, substances which influence soil fertility in an indirect manner, and which are consequently known as *indirect* manures.

It sometimes happens that a direct manure, when applied to the soil, exerts also an indirect influcnce. An example of this is furnished by farmyard manure, of which it may be said that its indirect value on many soils is quite as great as its direct one. Again, there are soils so poor in lime that they have actually not sufficient for the requirements of plant growth, and, in such a case, lime may act in a double capacity. Such soils are very rare.

Manures are further classified according to their source, such as *natural* and *artificial*, *mineral* and *vegetable*, or according to the number of fertilising ingredients they contain—*general* or *special*. We shall, in the first place, proceed to deal with manures which belong to the direct class, and which are valuable from the fact that they contain nitrogen, phosphoric acid, and potash in varying quantities.

CHAPTER IV.

FARMYARD MANURE AND SEWAGE.

In dealing with manures, farmyard manure merits consideration first of all, since it is not only the most widely used of all fertilisers, but is also the oldest. Its composition is by no means uniform, and probably no two samples would be found to yield, on analysis, the same result. This is due to a variety of causes. For one thing, the manurial value of the animal excrements, which form an important constituent of the manure, varies according to the food supplied to the animal—a rich food naturally producing a manure of greater value than a poor food.

Farmyard manure is made up of three ingredients, the *solid* and *liquid excreta* of animals, and the *litter* which is used to absorb them, and which, almost invariably, consists of straw, but sometimes may consist of peat-moss or other substance. The most valuable part of the manure is its liquid portion, which chiefly consists of urine, a substance rich in soluble nitrogenous compounds. And here it may be well to point out that the different foods in their passage through the animal system suffer comparatively little loss in respect of their fertilising constituents. Numerous experiments have shown that from three-fourths to nine-tenths of the nitrogen,

phosphoric acid, and potash which different foods contain may be recovered in the manure if it is properly treated. The proportion varies with the kind and condition of the animals fed. While foods, therefore, in their passage through the animal system suffer comparatively little diminution in the amount of fertilising constituents they contain, the condition of these fertilising constituents is considerably increased in value by the changes which they undergo; changes which render the manurial ingredients, especially the nitrogen, more speedily available for the plant's needs.

Straw, the common substance used as litter, possesses but small manurial value. On an average, it contains but little more than half a per cent. of nitrogen, and in the 5 per cent. of ash it contains only a fourth, or $1\frac{1}{4}$ per cent., consists of phosphoric acid and potash. It is a good absorbent, but where it can profitably be used for feeding purposes it seems a pity to use it as litter, especially where substances such as peat-moss or dried bracken may be easily obtained.

As farmyard manure is constantly undergoing rapid fermentative and putrefactive changes, and as the conditions under which it is generally kept render it liable to serious loss, great care should be taken in its treatment. The rate at which it decays depends on a number of conditions which do not admit of discussion in a small elementary treatise like the present. A most important influence is that of temperature, which requires to be carefully regulated to prevent serious loss. The most important loss, however, is apt to take place through the draining away of the black liquor, which becomes more abundant the longer the manure is kept. The com-

position of farmyard manure, as we have just said, varies considerably. The largest ingredient is water, which may be taken at from 55 to 80 per cent., rotted manure containing a larger amount than fresh manure. The amount of nitrogen present may be stated at about half a per cent.; the amount of potash being about the same, and the phosphoric acid somewhat less. A ton of farmyard manure will contain about 9 to 15 lbs. of nitrogen, about the same quantity of potash, and from 4 to 9 lbs. of phosphoric acid. What, then, it may be asked, are the characteristic qualities of farmyard manure as a fertiliser? As a direct manure—that is, as a supplier of plant food—it can scarcely be regarded as a concentrated fertiliser, seeing that it only contains about a twentieth of its total weight of such ingredients as are necessary for plant growth. Furthermore, with regard to the proportion in which it contains its fertilising ingredients, it may be said that this is not in the proportion in which most crops require these constituents. It may be said to be richer in mineral foods than in nitrogen. Again, the condition in which it contains much of that nitrogen is not one in which it is readily available to the plant. Much of it seems to become only very slowly available in the soil, and some of it may even take years before it is converted into nitrates. Yet, despite these facts, its properties as a manure are in many respects quite unique. As we have stated, its value must be largely held to be due to its mechanical and indirect properties. It may be considered to be better suited to restore to poor soils a state of fertility than any of the more concentrated and costly artificial fertilisers. The rate and period of year at which it may be applied, as well as the crops

which benefit most from its treatment, are important points, which, however, we shall reserve to a future chapter.

It has been the custom, in the past, to apply the liquid oozings from manure heaps, the drainings of farmyard byres, stables, piggeries, &c., directly to the soil. Indeed, so strongly has the belief in the superiority of liquid manure over the other manure been held by certain farmers that they have washed the solid excreta with water in order to extract from it its soluble fertilising constituents. Superphosphate itself, it may be added, was applied to the soil in a liquid form in the early years of its use. With regard to the merits of liquid manure, there can be no doubt that it is the most valuable form in which to apply manure, as it secures for the manurial ingredient it contains a speedy and uniform diffusion in the soil. On the other hand, many objections exist against its use. For one thing, the expense of distributing such a bulky manure is great. For another thing, it is not desirable to impoverish farmyard manure by removing from it that which promotes its fermentation, viz., the urine; and, lastly, it is apt to be a one-sided manure. If, however, the production of liquid manure on the farm is in excess of what can be used for the proper fermentation of farmyard manure it will be best to use it for *composts*.

The use of composts is an old one. Before artificial manures were so plentiful, much attention was paid by farmers to their preparation. A compost is generally made by mixing some substance of animal origin, rich in manurial ingredients, along with peat or loam, and often along with lime, alkali salts, common salt, or, indeed, any refuse which may be regarded as possessing

manurial value. It is a useful method of turning to profit refuse, of various kinds, accumulating on the farm. In composting, the object aimed at is to promote fermentation of the materials out of which the compost is formed, and thereby to convert their manurial ingredients into a condition available for plant needs. In short, farmyard manure may be described as a typical compost, and its manufacture serves to illustrate the principles of composting.

A manure regarding the value of which much discussion has taken place is *sewage*. Many attempts have been made in the past towards utilising the undoubtedly great quantities of fertilising constituents contained by it, with the result that its manurial value, from being formerly enormously overrated, has probably now come to be underrated. So many considerations have to be taken into account, sanitary as well as economic, that the question does not permit of easy discussion. Many schemes have been proposed for utilising it as a manure. The difficulty in the successful application of the sewage of a large town consists in the fact that the amount to be disposed of is so enormous. This is the difficulty in irrigating land with sewage. To properly utilise the sewage of a large town, enormous tracts of land would be required. The *sludge* resulting from the treatment of sewage with various chemicals possesses manurially little value. The most profitable method of treating sewage must be determined by various local considerations. It must clearly be understood that the question of sewage disposal is primarily a sanitary one, and that any method which does not comply with sanitary requirements should not be practised. For utilising its manurial

value a combination of chemical precipitation and land irrigation is, in most cases, doubtless the most profitable. Up till now it has been chiefly employed in this country by market gardeners for irrigating meadows.

CHAPTER V.

GUANO.

Guano is a fertiliser which at one time was used in this country to an enormous extent, but which of late years, owing to its chief sources of supply being well-nigh exhausted, is now only available in comparatively small amounts. It was the first artificial manure to be used in large quantities in this country, and its influence on agricultural practice has been very great, as it has led the way to what is known as *intensive* farming.

Guano is the excrements of sea-birds. Under the influence of a tropical sun, and in countries where rain is hardly known, these excrements soon become dried, and remain little changed in composition through centuries.

Guano deposits have been found in various parts of the world, the largest and most valuable being those in Peru, in South America. This is due to the fact that, owing to the dry climate of that part of the world, the guano has retained most of its original nitrogen. Guano is found in other parts of the world, where, owing to the dampness of the climate, it has lost all or the greater part of this its most valuable manurial constituent. Certain of its other manurial constituents are generally found to be wanting in such guano, which depreciates its fertilising value. The result is that very considerable difference has existed in the composition of the different kinds of guano

which have been used in the past. These have varied in composition from the rich Peruvian deposits, containing a high percentage of nitrogen, down to the purely phosphatic guanos, which have lost all their nitrogen.

Guano deposits have been chiefly found on the south-east coast of South America, or on small adjacent islands, the most valuable deposits ever found being those on the Chincha Islands, three small islands off the coast of Peru, which alone furnished, during a period of thirty years, over *ten million tons* of this valuable fertiliser. The deposits vary in depth from a few feet to several hundreds. In appearance guano varies somewhat. Its colour is from a light to a dark brown, and it possesses a characteristic pungent odour. The value of most guanos is due chiefly to the nitrogen and phosphoric acid they contain, and also to a small percentage of potash. As has been pointed out, many guanos only contain phosphates. Such guanos are not generally used directly as fertilisers, but are converted into dissolved manures.

What is especially characteristic of this valuable manure is the fact that it contains its fertilising ingredients in a variety of conditions. This is especially the case with its nitrogen, which is present in a large variety of more or less easily soluble forms. Some of it is in a condition in which plants can immediately absorb it; while the rest is in a series of less and less available forms, which, however, are gradually converted into available forms as the plant requires them. With its phosphoric acid the same is the case, though to a less extent.

The great inequality in the composition of guano has, of late years, led to the introduction of "dissolved" and

"rectified" guanos. Such guano consists of that which has been treated with sulphuric acid for the purpose of increasing the manurial action of its fertilising ingredients, especially its phosphoric acid; or that to which sulphate of ammonia has been added to bring up its percentage of nitrogen. A guano of a uniform composition may thus be produced, and the composition of which resembles that of the older rich deposits, now exhausted. It need scarcely be pointed out, however, that such a guano differs considerably in its action from the genuine article.

Peruvian guano, as now commonly sold, is of two kinds, the first class being guaranteed to contain from 6½ to 7½ per cent. of nitrogen (equal to from 8 to 9 per cent. of ammonia), 30 to 35 per cent. phosphates, and 2 to 3 per cent. of potash; while the second class contains only about half as much nitrogen (between 3 to 4 per cent.), but the phosphates are somewhat higher, 35 to 40 per cent.

The great popularity of guano has led to the application of the name to a number of manures. Of these *fish guano* and *meat-meal guano* are the best known examples.

Fish guano is a manure which is either made of fish, which, from various causes, cannot be used as food, or from fish-offal, obtained as a bye-product at fish-curing stations. The use of this manure is largely increasing, and there can be no doubt that it forms a valuable fertiliser. Its quality depends on how it is manufactured, and whether it is made from whole fish or from fish scrap. The general method of manufacture consists in extracting the oil from the fish, which are then dried and reduced to powder. In America it is largely manu-

factured from the *menhaddo*, a coarse sort of herring, which is caught for the sake of its oil; while in Norway, where fish guano has hitherto been chiefly manufactured, it is sometimes made from the carcass of the whale.

The best quality of fish guano may be said to contain from 8 to 10 per cent. of nitrogen, while the phosphates may vary from 4 to 15 per cent. Its composition, however, is very variable—the richer it is in nitrogen, as a rule, the poorer it is in phosphates. It also contains small quantities of potash. Fish guano, it must at once be said, is by no means so valuable a manure as genuine guano. Its fertilising constituents, especially its nitrogen, are not nearly so easily dissolved as those of genuine guano. When applied to the soil it is apt to decompose very slowly. This is due to the oil, which, despite the process of manufacture, is never wholly removed from the manure. It may be said that the less oil it contains the more rapidly will it become available. When used, the fact that it is slowly available should be borne in mind, and sufficient time should be given it to become properly fermented in the soil.

"Meat" or "meat-meal" guano is made from the refuse of the carcasses of cattle, after they have been treated for the meat-extract according to Liebig's process. It comes chiefly from South America, Australia, Queensland, and New Zealand, and, as commonly imported, contains from 4 to 8 per cent. of nitrogen—some of it occasionally containing as much as 11 to 13 per cent. The amount of phosphates in it varies, and is greatest in such samples as contain least nitrogen. Its percentage of phosphoric acid may be stated approximately at from 13 to 20 per cent.

In some parts of the world the carcasses of horses,

cattle, dogs, pigs, &c., which have died of disease are converted into guano. Such guano is similar in composition to that just mentioned.

Among other fertilisers similar in nature to guano which have been, and still are, used may be mentioned the dung of bats, pigeons, and fowls. All these are considerably inferior in value to either genuine guano or the so-called fish and meat guanos.

CHAPTER VI.

NITRATE OF SODA, SULPHATE OF AMMONIA, AND OTHER NITROGENOUS FERTILISERS.

THE most important of nitrogenous fertilisers is *nitrate of soda*—the substance which, along with sulphate of ammonia, occupies the position formerly occupied by Peruvian guano. This substance, which is imported in enormous quantities from the west coast of South America, where it is found in large deposits in Chili, is valuable only for the nitrogen it contains, which is in the most speedily available form for plant life. It is a white, crystalline substance, very easily soluble in water. The raw form, in which it occurs in South America, and which is known as caliché, contains only from 30 to 50 per cent. of the pure article, which has, therefore, to be obtained from it by refining processes. The ordinary commercial nitrate of soda contains about 95 per cent. of pure nitrate of soda—that is, about 15½ per cent. of nitrogen. Next to sulphate of ammonia, it is the most concentrated nitrogenous fertiliser. From the speed with which it becomes diffused in the soil, and from the fact that its nitrogen is in a form immediately available for absorption by the plant's roots, it should only be used as a fertiliser when the plant is ready to make use of it, and not beforehand, as is the case with most

fertilisers. It is, consequently, only applied in the form of a top dressing—that is, after the crop has developed to some extent. Among some of its benefits may be mentioned the tendency it has to encourage deep roots. It is best suited, perhaps, to exercise its full value in dry seasons, since the risks it runs of being washed away by rain is, under such circumstances, minimised; and, by inducing the roots of the plant to seek their nourishment at greater depths in the soil than would otherwise be the case, it enables them to withstand more successfully the action of drought. The old charge brought against it—that it is an exhausting manure—is, in the light of a wider knowledge of the subject, being largely abandoned. In order to exercise its full value, it must always be remembered that a plentiful supply of the other fertilising constituents is necessary. It can only be regarded as exercising an influence during the first year of application.

Sulphate of ammonia, the other great nitrogenous manure, is only second in importance to nitrate of soda, and has long been in use. While its nitrogen is not in such an available form for plant uses as the nitrogen in nitrate of soda, in several respects sulphate of ammonia may be regarded as possessing superior properties to nitrate of soda. For one thing, it is not so liable to be lost through drainage as is the case with nitrate of soda. For another thing, it is a more concentrated manure, being, indeed, the most concentrated of all nitrogenous manures. It is, like nitrate of soda, a whitish, more often greyish or brownish, crystalline salt, extremely soluble in water. The commercial article contains about 20½ per cent. of nitrogen, that is to say, about 5 per cent. more than nitrate of soda. Three tons

of sulphate of ammonia, therefore, would contain the same quantity of nitrogen as 4 tons of nitrate of soda. The oldest and what is still one of the chief sources of this valuable salt is the gas works, where it is obtained as a bye-product in the manufacture of coal gas. It is also obtained, although to a less extent, from coke and carbonising works. The dry distillation of bones, horn, leather, and other substances rich in nitrogen in certain manufactures also yields sulphate of ammonia as a bye-product.

Although not liable to be immediately washed out of the soil by rain after application, it is yet under most circumstances so speedily converted into nitrates that hardly less care should be taken in its application than in that of nitrate of soda. The mode in which this conversion takes place, known as nitrification, has been already described, so that there is no need to further refer to it here. The relative merits of these two great nitrogenous fertilisers have been made the subject of many carefully conducted trials. The results of these seem to point to the fact, that nitrate of soda is more likely to prove itself the more economical manure of the two in dry seasons; while the reverse is the case with sulphate of ammonia. It may be applied at least a month earlier than nitrate of soda.

While the manures we have just been discussing, viz., sulphate of ammonia and nitrate of soda, constitute the largest sources of nitrogenous fertilisers, there are a number of nitrogenous manures which, although used to a smaller extent, are of considerable value. Among these may be mentioned *dried blood*, *horns*, *hoofs*, *shoddy*, *scutch*, *rape dust*, *&c.*

The first mentioned of these, dried blood, is a

very concentrated and valuable fertiliser, and has long been used as such in France. The commercial article contains on an average about 12 per cent. of nitrogen, and about 1 per cent. of phosphoric acid. It is a quickly acting manure, since when added to the soil it rapidly ferments. The nitrogen it contains, although less rapidly available than that in nitrate of soda or sulphate of ammonia, may be described as equal to that in Peruvian guano. It is imported in large quantities from America, as well as manufactured at home. While peculiarly suited for horticulture—it is chiefly used in this country as a manure for hops—it has been applied with much benefit to wheat, grass, and turnips. On sandy or loamy soils it will be found to exert its maximum effect. Considerable quantities are exported to the sugar-growing colonies as a manure for sugar cane.

Horns and hoofs form a regular source of nitrogenous fertilisers. The quantity of nitrogen they contain varies very considerably, and may be approximately stated at from 7 to 14 per cent. Unlike dried blood, they are very slow-acting manures, and hence very inferior in value to that article. They have also been used with benefit for the hop crop. The same may be said of shoddy, the name applied to a manure made from waste wool products, and largely manufactured in this country. Its composition varies within considerable limits, low qualities containing only a small percentage of nitrogen, while the higher qualities contain from 8 to 12 per cent.

Scutch is the name given to the manure made from the waste products incidental to the manufacture of glue in the dressing of skins, and may be described as containing 7 per cent. of nitrogen. All these manures, with

the exception of dried blood, are better suited, on the whole, for application to such a crop as hops, or in the case of market gardening, where it is desired to have a bulky manure and to accumulate large quantities of decomposing organic substances in the soil. Among other minor nitrogenous manures may be mentioned rape dust, containing about 5 per cent. of nitrogen, a valuable manure; soot, a manure which has long been used, and which contains about 3 per cent. of nitrogen, but which varies very much in composition.

CHAPTER VII.

BONES.

THE value of *bones*, in the form of *bone-meal*, *bone-dust*, *dissolved bones*, &c., as a fertiliser, has long been recognised. Indeed, bones were used in England as early as the end of last century, at a time when no other artificial fertiliser was used, and they are still regarded as one of the most valuable of manures. They were at first applied in a comparatively coarse condition; but we now know that their action, when applied in such a form, is very slow, as pieces of bone may lie in the soil in an undecomposed condition for years. The common forms in which they are at present applied are as bone-meal or bone-dust. Bones, before conversion into bone-dust, should be boiled to remove the fat, which is apt to retard their decomposition when applied to the soil. Bone-meal or dust, of a first-class quality, contains from 45 to 50 per cent. of phosphates, and about 3½ per cent. of nitrogen. It may be added that the finer their state of division the more speedy their action. Even in a very fine state of division, they are a slow-acting fertiliser. It has, therefore, long been the custom to treat them with sulphuric acid, to dissolve the insoluble phosphate. Such bones are known as "dissolved bones," and generally contain about 20 per cent. of soluble phosphates. "Dissolved bones" are not to be confused with

"dissolved bone compounds," which contain other constituents in addition to bones, and which are largely in use.

The great popularity of bones as manure among farmers is doubtless due to the fact that their action in the soil continues for a longer time than most manures. When in an undissolved condition, they should always be applied to the soil a considerable time before they are likely to be needed by the growing plant, so that their fermentation may be well started, and the plant food they contain be partly in an assimilable condition before plant-growth starts. Indeed, it was formerly the custom, before they were ground to such a fine state of division, to ferment them before application, by allowing them to lie in heaps for a week or two in a damp condition. Sometimes the fermentation was further promoted by sprinkling the heap with urine or other refuse matter. Of all crops, permanent pasture is best suited to benefit by bones, and they are consequently most largely used for this purpose. "Dissolved bones," however, may be described as a quick-acting manure. "Dissolved bone compounds" may be made from a variety of materials, such as shoddy, wool waste, dried blood, fish guano, &c., along with bones. The composition of such manures varies considerably, and their value depends on this, and on the nature of the material used.

It is an open question whether bones have not been in the past, as a rule, over valued by farmers. They give, no doubt, what has been termed "backbone" to a soil, but the tendency of modern agricultural practice is to use quick-acting manures rather than slow. The economy of putting much capital into the soil in the form of such slow-acting manures as undissolved bones may well be doubted.

The manures which give the speediest returns according to our modern notions ought to be regarded as the most valuable. On the other hand, it seems a pity to utilise for the manufacture of superphosphate the dearer bones as raw material when the cheaper mineral phosphate may be had. As we have pointed out, bones are commonly regarded as being specially beneficial to pasture land, to which they are applied as a top dressing. In America they have been extensively used, mixed with wood ashes, as a substitute for farmyard manure.

Other substitutes derived from bones which are used as fertilisers or for manufacturing fertilisers are bone ashes, obtained from burning bones. That substance is extremely rich in phosphates, containing as much as from 70 to 80 per cent. of phosphate of lime; but is, of course, devoid of nitrogen. It is well suited for the manufacture of high-class superphosphates. Bone char or bone black is another article derived from bones. This substance is obtained when bones are heated in closed retorts, and is used largely as a filter in the filtration of sugar. After a time, however, it becomes unsuited for this purpose, owing to having undergone repeated heating. When this takes place it is technically known as *spent char*, and is used for the manufacture of superphosphate. Spent char may contain about 70 per cent. of phosphate of lime.

CHAPTER VIII.

SUPERPHOSPHATES AND MINERAL PHOSPHATES.

The chief sources of phosphatic fertilisers, in addition to guano and bones, which have already been mentioned, are the abundantly occurring *mineral phosphates*. The most abundant of these is *apatite*, which consists of calcium phosphate and small quantities of calcium fluoride and chloride. It is also known under the name *phosphorite*. While present in small quantities in most rocks, it is found in certain parts of the world in large masses, being particularly abundant in Canada. It occurs chiefly in a crystalline form, but is also found in an amorphous form. In colour it may be white, red, brown, green, grey, or blue, and it may contain from 70 per cent. to 90 per cent. of phosphate of lime. It may be described as a very hard, insoluble form of phosphate, and is only valuable as a manure when dissolved in sulphuric acid. In addition to the Canadian mines, the chief deposits are at Estremadura, in Spain, and in Norway. Enormous quantities of superphosphate of lime have been manufactured from apatite during recent years, but, in view of the discovery of other abundant mineral phosphate deposits of a less insoluble nature, apatite has largely ceased to be used as a raw material in the manufacture of superphosphate. Very large quantities of mineral phosphates

have come from *South Carolina*, and for years have formed the largest source of phosphate of lime used in the manufacture of superphosphate. These phosphates are of two kinds, the so-called land and river phosphates, the latter being dredged from different rivers. Such phosphate contains from 50 per cent. to 60 per cent. phosphate of lime. Among the other phosphate deposits may be mentioned the *Belgian*, containing from 35 to 40 per cent. phosphates, *French phosphate*, which contains about 80 per cent., and *Florida phosphate.* The last-named deposits have only been discovered a few years ago, and have been found to be of enormous extent, and for the most part of high quality. Like the South Carolina phosphates, they are of two classes, land and river phosphates, the former containing from 70 to 80 per cent., and the latter about 50 per cent.

Among other phosphatic deposits reference may be made to the so-called *coprolites*, or phosphatic nodules, found in large quantities in the green-sand formation, in the crag of the eastern counties, and in the chalk of the southern counties. They are composed of the fossil excrements and remains of ancient animals, and are in the form of rounded nodules. They have also been found in France. English coprolites contain from 50 to 60 per cent. of phosphate of lime; while the French are somewhat poorer, containing only about 45 per cent. The above-mentioned mineral phosphate deposits, along with the so-called "crust" guanos—that is, guanos containing only phosphate of lime, and which are found in the West Indian Islands and elsewhere — furnish materials for the manufacture of the largest used of all artificial fertilisers, viz., *superphosphates.*

While certain mineral phosphates, if ground fine enough, applied in certain circumstances and to certain soils, in an undissolved state, have been proved by numerous experiments to possess considerable value, yet it has long been recognised that for general use the only economical method of using mineral phosphates is in a soluble condition—that is, after treatment with sulphuric acid. Liebig was the first to discover that the effect of adding oil of vitriol to bones was to render the phosphate soluble, and this discovery may be said to mark an epoch in the history of fertilisers. The treatment of mineral phosphates with sulphuric acid soon followed, and now probably more than a million tons of superphosphate are annually made in this country; while the amount in the United States is considerably more.

Superphosphate of lime, as ordinarily manufactured, may be divided into three classes—low class, medium class, and high class; the quality of the phosphate depending on the quality of the raw material used, and on the care and efficiency with which the manufacture is carried out. The medium quality contains from 25 to 27 per cent. of "soluble" phosphate, the low class less than 25 per cent., while the high class contains from 30 to 45 per cent. The value of superphosphate as a manure may be ascribed not merely to the readily assimilable condition which its phosphate assumes when applied to the soil, but also to the intimate nature of its mixture with the soil particles which is thus effected. When it is added to the soil, being soluble in water, it is soon dissolved and carried down by the rain into the pores of the soil. At the same time, it is speedily converted from a soluble to an insoluble condition—that is, a precipitation of the phosphate takes place, due to the lime, iron,

and alumina salts which the soil contains. The question may naturally be asked—If this is so, why is it worth while to be at the trouble and expense of dissolving the phosphate? To this the answer is twofold. In the first place, it has to be pointed out that the insoluble condition into which superphosphate is converted when applied to the soil is a form of phosphate which, while insoluble in water, is yet much more readily assimilable by plant roots than the ordinary insoluble phosphates, out of which the superphosphate has originally been manufactured. It is, indeed, an intermediate stage between the ordinary bone phosphate and the superphosphate. Secondly, the result of adding it in a soluble form is to effect its admixture with the soil in a state of division infinitely more minute and intimate than could in any other way be obtained. Hence precipitated phosphate—that is, phosphate obtained under conditions similar to those obtaining in the soil—although in an equally fine state of division, cannot possibly be so intimately mixed with the soil particles. For these reasons it will be easily seen that the rate of action of superphosphate must always be quicker than that of any other form of phosphatic manure. The phosphate is uniformly distributed in the soil, and the plant roots are thus furnished with a continuous supply throughout their growth, regularity in which is thus secured, a point of great importance. Moreover, micro-organisms, which require for their development a supply of this necessary plant food, are propagated.

A phosphatic fertiliser which has recently come into the market is *basic slag* or *Thomas phosphate.* This substance is a bye-product obtained in the manufacture of steel by the so-called basic process. It

consists mainly of phosphate of lime, silicate of lime, free lime, and free magnesia, with oxides of iron and manganese. The amount of phosphoric acid it contains may be said to vary from 10 to 20 per cent., equal to from 22 to 44 per cent. tricalcic phosphate. Its phosphoric acid is combined with the lime, not, however, in the form of tricalcic phosphate, but in a new form unknown except in this compound—viz., tetracalcic phosphate. Various processes have been tried for preparing the slag as a fertiliser. These, however, have been found to be for the most part unsuccessful; the best and most economical method being to apply it in a state of very fine division. Indeed, unless ground to a very fine powder, it may be said to possess little fertilising value. When ground, however, to such a state of fineness, that 80 per cent., or thereabouts, passes through a fine gauze sieve containing 250 wires to the linear inch, it is found in many soils to be a manure of considerable value. Its efficacy has been calculated to be about half that of superphosphate. Its action as a manure is much more favourable on some soils than on others. Those best suited to benefit from it are peaty soils, poor in lime. It should be applied in considerable quantities, and some time before it is likely to be required by the crop.

CHAPTER IX.

POTASH FERTILISERS.

THE use of potash fertilisers is very much more limited in extent than either nitrogenous or phosphatic. As a rule, potash does not require to be applied to the soil in the form of a fertiliser to the same extent as nitrogen or phosphates. Indeed, in many cases, the addition of potash has little or no effect on the fertility of the soil. The reason of this is that many soils, more especially clayey soils (but not necessarily always), are well supplied with potash. On the other hand, there are soils which are greatly benefited by the addition of this fertiliser. Among those may be mentioned sandy, chalky, or peaty soils. We must also remember that under the ordinary conditions of farming the tendency is towards an accumulation of potash in the soil. Where large dressings of farmyard manure are applied, the soil receives much potash. On the other hand, whenever forage crops or straw are sold off the farm in large quantities, or where beets, cabbages, carrots, potatoes, onions, etc., are grown in large quantities, the necessity for potash manuring arises. This is specially the case with potatoes, which benefit more by potash than any other crop.

The value of potash as a fertiliser first came to be realised by the favourable action of wood ashes, in which

it is the dominant fertilising constituent. As, however, the supply of substances suitable for use as potassic fertilisers is in excess of the demand, only the more concentrated substances are used. These are chiefly obtained from the Stassfurt deposits, and consist of *kainit*, *sulphate*, and *muriate of potash*. Kainit, which may be described as an impure form of sulphate of potash, contains, on an average, about 12 per cent. of potash; whereas the muriate or the sulphate, as commercially sold, contains about four times that amount. In all three forms the potash may be said to be in a readily available form for plant uses; but, inasmuch as this substance is retained by the soil particles, it ought to be applied to the soil some time before it is likely to be required by the crop. Speaking generally, it may be said that potash benefits crops of the leguminous order most.

Under the heading of potash manures we may consider one which is largely used in maritime agricultural districts—viz., *seaweed*. In a fresh condition, this manure may be described as containing about 3 per cent. of potash, and about half of that amount of nitrogen, with a fraction of a per cent. of phosphates. Its manurial value and action are generally reckoned as similar to that of farmyard manure; but this is perhaps hardly correct. It no doubt, however, forms a valuable manure.

CHAPTER X.

INDIRECT MANURES—LIME, GYPSUM, SALT, ETC.

THE indirect manures are those the value of which is due not to their direct action as suppliers of plant food, like those previously discussed, but to their indirect action. Of these, *lime* is the oldest, and one of the most important. Indeed, the use of lime is of great antiquity, and its action is at once complicated and many-sided. There are soils—though by no means of common occurrence—which lack a sufficient supply of lime for promoting plant growth, and to which its addition directly aids the growth of the crop. Poor sandy soils are of this nature; so, also, are peaty soils.

The action of lime is, as we have said, many-sided. The benefit derived by permanent pasture soils from an application of this manure is often of a striking nature. The surface of such soils, in the first place, is apt to lack a sufficiency of lime from the fact that this ingredient has a tendency to sink down to the lower layers of the soil. In ordinary arable soils this tendency is largely counteracted by tillage operations, in which the lime is again brought to the surface. In pasture soils, however, no such counteracting influence is at work; hence the impoverishment in lime of the surface

soil results. Lime also seems to have a striking effect in improving the quality of pasture by inducing the finer grasses to predominate. Especially does it promote the growth of white clover.

It is used in agriculture in different forms—viz., as *carbonate*, or *mild lime* as it is commonly called; *burnt*, *caustic*, or *quick lime;* and as *gypsum.* Gypsum will be treated immediately by itself, so that we shall only deal here with caustic lime and mild lime.

The method in which these two forms of lime act is to some extent similar, the only difference being that in the burnt or caustic form its action is somewhat more intense. When lime is applied in a caustic state to the soil, it slowly absorbs carbonic acid gas, and becomes converted into the mild form, and to this change some of its effect is due. It may be said to act upon a soil both mechanically and chemically, by altering its texture and affecting its physical properties, such as its absorptive, retentive, and capillary powers with regard to water, and by acting upon its dormant fertilising ingredients, and decomposing its mineral constituents as well as its organic matter, and, finally, by exerting an influence upon the development of micro-organic life, and in this way playing an important part in the preparation and elaboration of plant food.

It is rather a striking fact that its action on different soils seems to vary in its nature. Thus, when applied to a stiff clay, it effects a change in its texture by lessening its adhesive properties, that is its objectionable tendency to puddle when mixed with water, and by rendering it much more friable when in the dry

state. This it effects by causing a flocculation or aggregation of the fine particles, and by rendering the clay less liable to shrinkage in dry weather. This latter effect of lime is seen in the case of even very small additions, and is what is meant when it is stated that lime has a *lightening* effect on soils. On the other hand, however paradoxical it may seem, it would appear that its influence on a light soil is of very much an opposite nature, since it seems to increase the cohesive power of such a soil. Indeed, this binding influence of lime takes place in some soils, rich in it, to such an extent, that a hard cake is formed, known as a lime-pan.

But more important than even its mechanical effect is the chemical action of lime, for it is a most important agent in unlocking the inert fertility of the soil. This it does by decomposing different minerals and setting free the potash they contain. In this action, caustic lime is much more potent than mild lime. On vegetable matter it exercises a similar decomposing effect, and renders the inert nitrogen it contains available for the plant's use. This may be described as one of the most important effects of lime, and accounts for its beneficial action when applied to soils (such as peaty ones) rich in organic matter. Its use as a corrective for sour lands has long been recognised. Acidity in a soil is hurtful to vegetable life; and lime, by neutralising this acidity and removing the sourness of land, does much to restore it to a condition suitable for the growth of cultivated crops. In such soils compounds poisonous to plant life are apt to be formed; by the addition of lime the conditions favourable to the formation of those compounds are removed. Its application to badly

drained meadow land not merely ameliorates the general condition, but also checks the growth of the coarser and lower forms of grasses, and promotes the growth of the more nutritive and valuable grasses. Lime also gives rise to the formation of a class of compounds of great importance in the soil—viz, hydrated silicates, compounds which retain or fix the available mineral fertilising matter and prevent it from being washed into the drains.

What has been called the biological action of lime is also highly important, although its value in this respect has only been comparatively recently recognised. The presence of carbonate of lime in the soil is, as has already been pointed out, a necessary condition for the important process of nitrification. It furnishes a base with which nitric acid can, when formed, combine. A certain amount of alkalinity is necessary for fermentative action of the organic matter; and lime, by furnishing this alkaline reaction, directly promotes its decomposition in the soil.

In applying lime, care must be had not to do so too often, or in too large quantities, and to have due regard to the nature of the soil; indeed, it is a manure which can only be applied with great care and discrimination. It should never be applied along with, or even shortly before, certain nitrogenous manures, such as sulphate of ammonia, or any manure containing ammonia, since the result would be to dissipate this most valuable form of nitrogen.

Gypsum has been so long in use as a manure that it merits description by itself. In some respects its action is similar to that of other lime compounds; in other respects it is quite different. Its valuable and character-

istic action is probably due more to its sulphuric acid than to its lime. It acts as a fixer or absorber of ammonia; it decomposes the double silicates in the soil and sets free the potash. Indeed, an application of gypsum practically amounts to an application of potash in many soils, and the valuable and striking effect it has in promoting the growth of clover may be accounted for in this way. Experiments have shown that it exerts a very favourable effect on the process of nitrification. It is highly probable, also, that its effect as an oxidising agent in the soil may explain the favourable nature of its action.

The only other indirect manure which we may here mention is *salt*. Its fertilising effect, when applied to the soil, has been noted from the very earliest times, although its merits have been variously estimated. Its action may be well described as a most complicated one, and often may be far from beneficial. It is, as a rule, only applied along with other manures. Its mechanical action is probably similar to that exerted by lime, inasmuch as it causes a similar flocculation or coagulation of the fine particles when applied to a clayey soil. Likewise, it exercises a solvent action on the inert plant food, and liberates the necessary mineral constituents from their compounds. Nor must its antiseptic properties be lost sight of, and this no doubt accounts for the beneficial action it has when applied along with Peruvian guano. It is often applied along with nitrate of soda. Plants of the cabbage tribe seem to benefit much by it, so also do mangolds. Both on the beetroot crop and on the potato crop its action, however, is deleterious, since it has been proved to affect the percentage of sugar in the former, and the percentage

of starch in the latter. Light, sandy soils are more likely to benefit by it than heavy soils. It may be said that its action as a manure is as yet ill understood, but that on certain crops, such as cabbages, it is undoubtedly beneficial.

CHAPTER XI.

THE COMPOSITION AND APPLICATION OF FERTILISERS.

It cannot be too clearly emphasised for the guidance of the agriculturist that the value of a fertiliser as a commercial article depends on the percentage of nitrogen, phosphates, and potash it contains, as well as the chemical condition of these different fertilising constituents. Since these facts can alone be determined by a chemical analysis, it is obvious that manures should always be purchased on this basis. It is an unfortunate fact that a chemical analysis, even when procured, is not always very intelligible to one ignorant of chemistry. By means of the Fertilisers and Feeding Stuffs Act recently introduced, any farmer can have his fertilisers tested by agricultural analysts specially appointed by the County Councils for, in most cases, a trifling fee. In such a case the only constituents of the fertiliser tested for are nitrogen, phosphates (soluble and insoluble), and potash, and every manure vendor is compelled to give a guarantee on selling the fertiliser of the percentage of these ingredients it contains. Should the result of the district agricultural analyst's analysis show the fertiliser to be under guarantee, the matter is reported to the Board of Agriculture, which institutes a prosecution under the Act. No difficulty exists, therefore, in such a case, for the farmer in interpreting the

results of an analysis. But in many cases where a full analysis is given, and where the results are not stated so simply, a farmer is apt to be bewildered at the different figures given, and not clearly to understand the meaning of the analysis. One or two words, therefore, may be said in explanation of the method in which the results of an analysis are stated.

Discarding all other constituents except the nitrogen, phosphates, and potash as not affecting the commercial value of a fertiliser, a word or two may be said on the different forms in which nitrogen may be present. As was pointed out in speaking of the nitrogen of the soil, nitrogen may exist, broadly speaking, in three different forms—viz., as organic nitrogen, as ammonia, and as nitrates. Now, obviously the fact of first importance is to ascertain what the percentage of nitrogen in a fertiliser is. This should always be stated, whatever chemical form it is in—whether as nitrates, ammonia, &c.—and no doubt in the future this will be the case. Unfortunately, however, in the past, it has been common to state the nitrogen as ammonia, irrespective of the fact of whether it is present in the manure in that form or not. In a statement of analysis a manure was often said to contain so much ammonia, when in point of fact it contained no ammonia whatever.* With regard to phosphates there is not the same risk of misapprehension, seeing that the phosphoric acid is always

* In order to calculate how much nitrogen a certain percentage of ammonia represents, all that has to be done is to multiply it by 14 and divide by 17, since 17 per cent. of ammonia is equal to 14 per cent. of nitrogen. If, on the other hand, it be desired to convert the percentage of nitrogen into the percentage of ammonia, multiply by 17 and divide by 14.

stated in its equivalent of tribasic phosphate of lime.

Having thus discovered, by inspection of the analysis, the amounts of these constituents, the question which the farmer should next seek enlightenment on is as to the condition in which they are present in the manure. Now, with regard to nitrogen, this is often not very clearly indicated by the analysis, but generally, even where the analysis does not specify its exact nature, this may often be inferred from the nature of the manure itself. In the case of such manures as sulphate of ammonia and nitrate of soda, no ambiguity exists. It is, however, in the case of mixed manures, somewhat different, and this, it may be remarked, is one of the objections against the use of mixed manures.

With regard to the value of different forms of nitrogen, we may say generally that that in the form of nitrates and ammonia, and in certain of the more easily decomposable organic compounds, such as dried blood, meat meal, and of Peruvian guano, is from a fertilising point of view of practically similar value. That their commercial value is not always the same is due to a variety of causes with which we are not here concerned. Of considerably less value is the nitrogen in steamed bone meal, fish guano, oil cakes, and the better kinds of artificial guanos; while of least value is that in bone meal, horn meal, woollen refuse, &c.

With regard to phosphates, commercially only two forms are recognised—viz., *soluble* and *insoluble;* but among the so-called insoluble phosphates considerable difference in value exists, the term "insoluble" being a comparative one. Thus, for example, very wide difference in their respective fertilising values exists between a

mineral phosphate, such as apatite, and precipitated phosphate. There is reason, also, to believe that the phosphates in basic slag, when that article is in a fine enough state of division, is more valuable than that in such a mineral phosphate as apatite. While, lastly, phosphate in such organic compounds as bones and guanos of various kinds, both natural and artificial, are, from the fact of their mechanical condition, and their being associated with large quantities of fermentable organic matter, more valuable as fertilisers than the mineral phosphates.*

For the purpose of affording *data* for ascertaining the approximate value of a fertiliser, tables have been drawn up giving what is called the "unit" value of the different fertilising ingredients in various fertilisers. This is obtained by dividing the market value of a fertiliser per ton by the percentage of nitrogen, phosphates, and potash it contains. Thus, for example, sulphate of ammonia of 97 per cent. purity contains 25 per cent. of ammonia, and is valued at £13 15s. per ton. In order to obtain the unit value of ammonia in sulphate of ammonia, we have only to divide £13 15s. by 25, which gives us 11s. The value of such tables, however, depends on the competence of those drawing them up; and they require to be subjected to constant revision.

A most important object in applying fertilisers is to effect equal distribution of the fertiliser in the soil. This

* It may be well to explain that the term "soluble" phosphate in the statement of an analysis really means the amount of tricalcic phosphate (*i.e.*, insoluble phosphate) which would be originally required to furnish the soluble phosphate present.

is often, however, difficult to do, especially in the case of artificial fertilisers, where the quantity to be spread over a large area of the soil is extremely small. The difficulty in the case of farmyard or other very bulky fertiliser is not so great. In order to overcome this difficulty in the case of artificial fertilisers, it is often advisable to mix them with some such substance as sand, ashes, loam, peat, or salt. The fertiliser is thus diluted in strength, and a very much larger bulk of substance is obtained to work with. Circumstances must decide *which* of these substances to use. If the soil be a heavy clay, the addition of sand or ashes may have an important mechanical effect in improving its texture; while, on the other hand, if it be a light soil, the addition of peat may improve its mechanical condition. It must also be remembered that peat itself contains a large amount of nitrogen, and thus forms a manure of some value. In using loam or peat to mix with artificial fertilisers, they should be first dried and then riddled; while if ashes be used, they should be previously reduced to a fine state. Wood-ashes, however, must be used with caution, and ought not to be mixed with ammoniacal fertilisers, as they are apt to contain caustic alkali, which would tend to drive off the ammonia.

It is to be feared that not unfrequently indiscriminate mixing of fertilisers may cause very serious loss in the most valuable constituent of a fertiliser. It may be well, therefore, to point out one or two causes of the loss that is apt to ensue on the mixing of different kinds of fertilisers together.

The risks of loss which may occur from the mixing of artificial fertilisers together may be of different kinds. One is the risk of actual loss of a valuable ingredient

through volatilisation; another is the risk of the deterioration of the value of a mixture through change of the chemical state of a valuable ingredient. Undoubtedly the most common and most serious source of loss is the former. Of the three valuable fertilising ingredients—nitrogen, phosphates, and potash—only the first is liable to loss by volatilisation, and this generally only when the nitrogen is either in the form of ammonia or nitric acid.

Ammonia, when uncombined, is a very volatile gas with a pungent smell, a property which enables its escape from a fertiliser mixture to be very easily detected. It belongs to a class of substances which are known chemically as bases, and which have the power of combining with acids and forming salts. Sulphate of ammonia, as its name indicates, is a salt formed by the union of the base (ammonia) with the acid (sulphuric acid). Now, when ammonia unites with sulphuric acid, and forms sulphate of ammonia, it is no longer volatile and liable to escape as a gas, but becomes "fixed" as it is called. Although most salts are more or less stable bodies—not liable to change—if left alone and not submitted to a high temperature or chemical action, they can be easily decomposed if they are heated or brought in contact with some other substance which will give rise to chemical action. Sulphate of ammonia is a salt that is very easily decomposed. This is due to the fact that its base (ammonia) is very volatile and not capable of being held very firmly by an acid, even by sulphuric which is among the least volatile of all the common acids. If, therefore, sulphate of ammonia be heated above the boiling point of water, or brought in contact with any other substance which will give rise to chemical

action, it is easily decomposed. Now a salt may be acted upon by a base, or an acid, or another salt. When it is brought in contact with a base, if the base with which it is brought into contact be a stronger base than the base of the salt, the salt is decomposed and a new salt is formed. The acid, in short, exchanges its old base for the new one.

This is exactly what takes place when the base lime comes in contact with an ammonia salt such as sulphate of ammonia. The sulphuric acid exchanges its old base, ammonia, for the stronger base, lime, and sulphate of lime is formed, the ammonia being set free as a gas, which escapes and is lost. Sulphate of ammonia, or any substance in which there is an ammonia salt, must never be brought in contact with free lime, otherwise the ammonia will be lost. It is entirely different with gypsum—which is sulphate of lime—or phosphate of lime, both of which may be safely mixed with sulphate of ammonia without any danger of escape of ammonia. It follows from the above that a mixture which must on no account be tried is slag phosphate and sulphate of ammonia. This is because the slag contains a large percentage of free lime, which would at once, on being brought in contact with the sulphate of ammonia, decompose it, and cause the ammonia to be lost. For this same reason guano must not be mixed with slag. If it be desired to mix the slag with a quickly available form of nitrogen, nitrate of soda is not liable to loss; although for other reasons it is not desirable to apply nitrate of soda along with the slag, as the former fertiliser should be applied almost always as a top-dressing.

The risks of the loss of nitrogen in the form of nitric

acid, although not so great as they are in the case of ammonia, are still considerable. As nitric acid is not a base but an acid, what is to be avoided in mixing nitrates is bringing them in contact with any other fertiliser, as for example superphosphate, which contains another free and stronger acid. The free acid in the superphosphate has the tendency to drive out the nitric acid from the nitrate and usurp its place. The risk of loss of expulsion in the above cases is always augmented by the rise of temperature which invariably accompanies chemical action of any kind; and although the loss of nitrogen, in the form of nitric acid, caused by mixing superphosphate and nitrate of soda, might, under ordinary circumstances, amount to very little, yet if the mixture were allowed to stand any time, and the temperature of the mass to be raised, the loss which would undoubtedly then ensue would be considerable. The nitrogen salt which it is safe to mix with superphosphates is sulphate of ammonia.

But, as has been already mentioned, there is another loss which may result from the mixing of fertilisers. This is the deterioration of the value of an ingredient by reason of change of chemical condition. This is a source of loss that was little suspected a number of years ago, but it is now well known that superphosphate of lime, under certain conditions, is changed from its soluble to an insoluble form. Reversion, as this form of change is called, is often caused by the presence of iron and alumina, or undissolved phosphate, and the risk of reversion is, therefore, very much less in a well-made article, made from pure raw material, than in one made from a raw phosphate containing much iron and alumina. Superphosphates containing a large percentage

of insoluble phosphates ought not to be kept too long before being used as a manure, otherwise much of the labour and expense involved in their manufacture will be lost by the reversion of their soluble phosphate. Further, it is highly inadvisable to mix superphosphate with basic slag, which contains a large percentage of both iron and free lime. Lastly, if it is desired to mix superphosphate with insoluble phosphate, the mixture ought to be made just previous to application.

The question of applying fertilisers in mixtures is one on which considerable difference of opinion may exist. For many reasons fertilisers are often better applied in the unmixed condition. For example, a mixture of a quickly acting nitrogenous fertiliser with a slowly acting phosphatic fertiliser is not suitable. In such a case, either the nitrogenous fertiliser will be applied too long before it is required by the plant, or the phosphatic fertiliser will not be applied long enough before it is likely to be used. By applying fertilisers in an unmixed condition, the chances are that a more economical use of them is made than would otherwise be the case. On the other hand, while the application of the separate constituents may be desirable from the scientific point of view, it involves a considerable amount of extra trouble. Of course, a further consideration is the desirability, in many cases, of having a complete fertiliser.

CHAPTER XII.

THE MANURING OF THE COMMON FARM CROPS.

SOME crops are removed from the farm, such as the cereals; while others are consumed on the farm, and the manurial ingredients they contain find their way back into the soil. Of the latter class of crops are roots, leguminous crops, and grass. The rotation of crops is thus a question which has an intimate relationship with the question of the application of fertilisers.

The influence of manuring, it must be at once stated, on what we may call the *permanent* fertility of the soil is very slight. It cannot be too strongly insisted upon that the fertile condition of a soil, once it has been exhausted by injudicious treatment, is extremely difficult to be restored, and can only be done by very gradual degrees. After all, when we reflect on the comparatively small quantity of fertilising constituents we add in the ordinary fertilisers, it is not astonishing that they should have but an insignificant effect in restoring an exhausted soil to a good condition. In fact, the very nature of the highly concentrated and quickly available artificial fertilisers now in use renders it impossible that they should directly affect the condition of the soil. The slow-acting fertilisers, whose influence tells through several years, are no longer regarded with such favour as they once were—and rightly so.

Of all fertilisers, farmyard manure may be said to have the best effect in influencing what we call the permanent fertility of a soil. This is owing to the fact that it is applied in such large quantities, as well as to the fact of its composition. Systematically carried out, liberal manuring will, in time, do much to build up a soil's fertility. But even with artificials the same end may be effected in an indirect way; for under a system of liberal manuring the quantities of produce of such crops as are consumed on the farm, as well as the residues of such crops as are removed, will be much greater.

It is not likely that farmyard manure will ever be superseded by artificial fertilisers. The proper and economical use for these latter consists in judiciously supplementing the former. Farmyard manure, we must remember, only returns, as a rule, to the soil what has come off it; and that minus a certain varying quantity which is lost in the transition. No doubt, under certain circumstances, where purchased foods, such as linseed cake, &c., are largely used, this loss may be largely made good; but it is rarely entirely made good. It is, therefore, to supplement farmyard manure that artificial fertilisers should be used. The nature of their action is in many respects so dissimilar that they may be regarded as complementary to one another.

In applying manures, consideration must not only be had to the crop to which the manure is applied, but to the whole rotation practised. Some crops are best adapted, for a variety of reasons, to benefit more by farmyard manure than others; while the application of farmyard manure to other crops is, under certain conditions, highly injudicious. Thus, it is inadvisable,

on strong, rich soils, to apply it to grain crops such as barley or wheat, since it is apt to encourage rankness of growth. Where the soil is a light one, the risk is not so great. Again, many are of the opinion that potatoes are similarly not benefited by the application of farmyard manure. In the most generally practised rotation of crops, the one, indeed, on which all others are based—or, rather, of which all others are mere variations—viz., the Norfolk, the farmyard manure is applied to the turnips, and not directly to the grain.

Furthermore, in the application of artificial fertilisers the nature of the fertiliser should be taken into account—that is to say, whether it is quick-acting or slow-acting. Nitrate of soda, for example, should only be applied as a top-dressing. Such a fertiliser as bones, on the other hand, should be applied some considerable time before the plant is ready to make use of them. Ammonia salts, while less speedily available for the plant's uses than nitrate of soda, is much more so than the nitrogen in such a manure as dried blood. So also with the different forms of phosphates, soluble phosphates being much more speedily available than insoluble. With regard to potash, it is a common experience that this, although applied invariably in a soluble form, is best applied a considerable time before it is likely to be used by the crop. Hence we find that fertilisers may be divided broadly into two classes—those which should be applied in autumn, and those which should be applied in spring. To the former class belong manures containing undissolved phosphate, basic slag, nitrogen in an organic form, shoddy, and potash manures; while to the latter class belong soluble

nitrogenous fertilisers, nitrates, ammonia, salts, guano, and soluble phosphates.

The nature of the soil must also be kept in view, as well as its previous treatment. Generally speaking, soils poor in organic matter are those which are most likely to be benefited by the application of nitrogenous fertilisers. Soils of a dry, light character require less phosphates than they do of nitrogen and potash. A soil rich in organic matter generally requires phosphates or potash. With regard to the application of phosphatic manures, a point of considerable importance in their choice is the nature of the soil to which they are to be applied. Where the soil is poor in lime there is a certain risk in applying acid phosphate. In such a soil it is preferable to use a phosphatic manure of the nature of bones or slag or guano. If, however, there is a sufficiency of lime in the soil, the dissolved phosphate is to be preferred. The nature of the season is also a matter of importance. For instance, in a very wet season it has been found that such a manure as sulphate of ammonia has a better effect than nitrate of soda. To a light and non-retentive soil the risk of loss in applying certain kinds of soluble manure is considerably increased. The previous treatment of the soil with manure has also to be taken into account. A soil liberally treated with farmyard manure is especially benefited by the application of artificial nitrogenous fertilisers. As has been already indicated, the effect of most fertilisers is chiefly seen on the crop to which they are directly applied. Some, however, exert a more lasting influence. As manures which have no influence beyond the first year of application may be mentioned nitrate of soda and sulphate of ammonia. On the other

hand, bones, slag, &c., may exercise an influence for several years following their application. For the purpose of compensating a quitting tenant of a farm for the value of unexhausted manures, the Agricultural Holdings Act has been framed. The working of the Act, however, has been found to be surrounded by extreme difficulties, as is only natural.

In conclusion we may say a word or two on the manuring of the more common farm crops.

We may start with *cereals*. To this class belong barley, wheat, and oats. A certain similarity in the manurial requirements of the different members of this class exists. For one thing, they are characterised by the comparatively small quantity of nitrogen they remove from the soil, which is considerably less than either of the other classes of crops—leguminous and root crops. Of this nitrogen the larger portion, amounting to two-thirds, is contained in the grain. The amount of phosphates they remove, however, is not much less than that removed by the other two classes of crops. This, again, is also chiefly in the grain. It is on this account that the cereals may be regarded as exhaustive crops, seeing that the grain is sold off the farm. As cereals constitute a very important element of human food, arable farming in the past has been carried out with a view to growing such crops in a manner least exhaustive to the soil. Before the rotation of crops was introduced it was customary to grow cereals for a number of years in succession, and then to have recourse to bare fallow, or in some cases to abandon the land to the growth of rough herbage. An advance in this practice is marked by the introduction of alternating leguminous crops with cereals. The introduction of such a crop has

very much the same effect in resting the land as fallow has, besides being much more economical. The introduction of roots into the rotation marks a still later improvement. It is a curious fact, however, that although cereals may be regarded as distinctly an exhaustive crop they will yet continue to grow on poor land for a longer period than most crops

It has been already pointed out that in judging of the manurial requirements of a crop attention must be had not merely to the absolute amount of fertilising ingredients such a crop removes from the soil, but also to the ability of the crop to absorb from the soil these fertilising constituents. Now, although cereals remove comparatively little nitrogen from the soil, they are most benefited by the application of nitrogenous fertilisers. This fact may be explained by the shortness of their period of growth, and also by the fact that they assimilate their nitrogen in spring and early summer, and are thus enabled to utilise to the full the nitrates which accumulate in the soil, due to the process of nitrification, in later summer and autumn. The special fertiliser, therefore, required for cereals is a nitrogenous manure, and that of a speedily available character. But while the different members of this class resemble each other in several points, they have their special characteristics, which we will now notice.

Barley, like oats, has a very short period of growth. In this country barley may be said, on an average, to ripen in thirteen or fourteen weeks. It is a spring crop, and from the fact that its roots, which are shallower than wheat, draw their nourishment chiefly from the surface soil, benefits much from liberal manuring. It does best on a light, rich, friable soil;

and while, like the other members of the cereal group, it especially benefits by a nitrogenous manure, such as nitrate of soda, applied as a top dressing, it also responds to the application of superphosphate of lime. Indeed, it may be said that spring-sown crops, as a rule, benefit more from superphosphate than autumn crops. The exhaustion of a soil under barley is one of nitrogen. Barley is not suited to benefit by the direct application of farmyard manure. The use to which barley is put—viz., malting purposes—renders uniformity in its composition of importance. Since its quality is very largely influenced by its treatment with manure, special attention has to be exercised in their application. Care, therefore, must be taken not to manure too richly barley which is destined for malting purposes. Barley is often grown immediately after wheat crops, and occasionally without manure, where the land is rich. It is claimed that barley, grown under such circumstances, will be best for malting purposes. The amount of the manure to be applied to any crop will necessarily depend on the treatment of the land throughout the rotation. In experiments carried out in Norfolk it was found that from $\frac{1}{4}$ to 1 cwt. of nitrate of soda, according to the previous treatment of the soil; from 1 to 2 cwt. of superphosphate; and, where required, from $\frac{1}{2}$ cwt. to 1 cwt. of muriate of potash, were suitable quantities of fertilisers to apply to the barley crop.

Wheat, unlike barley, is generally sown in autumn although it is also sown in the spring. Unlike barley, it does best on a clayey soil, and requires a moist seed-bed. As it often follows a crop which has been heavily manured, it is not so necessary to manure it. Indeed, the only manure generally applied is a top dressing of

nitrate of soda. It is usually considered highly desirable to get land into good "heart" before wheat. On a light soil, however, it may often be desirable to add superphosphate of lime or guano or some other phosphate manure at the rate of from 2 to 3 cwt. per acre. The quantity of nitrate of soda applied as a top dressing varies from $\frac{1}{4}$ cwt. to 1 cwt. per acre.

It may be mentioned in passing that the possibility of growing fair crops of wheat continuously on the same land for a period of fifty years has been demonstrated by the famous Rothamsted experiments.

Wheat is generally grown after clover or other leguminous crop to which farmyard manure has been applied. Such a crop, by its ability to fix the atmospheric nitrogen, and to draw nitrogen from the subsoil, serves to greatly enrich the surface soil in that fertilising constituent. A large clover crop is thus an admirable preparation for a wheat crop. Where the previous crop has not been liberally treated with manure, it may be well to manure the soil with phosphates in autumn, before the wheat is sown. As a rule, it is advisable to top-dress wheat with nitrate of soda in spring—about 1 cwt. of nitrate per acre being sufficient.

Oats, like barley, are a shallow-rooted crop, and require manures which are readily available. They may be treated very similarly to barley. Perhaps on no crop is nitrate of soda so safe and so effective a manure. Superphosphate of lime may also be applied with advantage along with the seed. In some respects oats are different from barley. For one thing, they are a much hardier crop than barley, and they can grow on a wonderfully large variety of soil, and under comparatively adverse circumstances both of climate and situation.

They are well suited for a damp climate, and flourish on sandy, peaty, or clayey soils. They show a preference, however, for soils rich in decayed vegetable matter. It is for this reason that they flourish so well in soils freshly broken up from pasture, and are often the first crop to be grown on such soils.

Oats absorb nitrogen during nearly the whole period of their growth. By some it has, for several reasons, been considered advisable to manure them with a mixed nitrogen manure, containing nitrogen in different conditions of availability.

The quantity of manure which should be applied to the oat crop is similar in amount to that applied to the other cereal crops. Often, indeed, the oat crop is not manured at all.

We may next consider the manuring of *grass*. Grass is grown under two conditions—viz., on soils set apart for its continuous growth (permanent pasture); or it is grown for the purpose of being converted into hay, and providing pasture in the ordinary rotation of crops (rotation seeds). The manuring of the former differs from that of the latter. Rotation grasses may be liberally manured. Permanent pasture, on the other hand, requires very careful and judicious treatment. It is a curious but well ascertained fact that the nature of the herbage growing on pasture is very much influenced by the fertiliser used. The herbage constituting pasture is, as every farmer knows, of a varied description. We have in pastures a mixture of plants belonging both to the gramineous and leguminous classes, as well as a variety of weeds. Now the result of the application of different manures tends respectively to foster the different kinds of grasses. Thus, when one kind of manure is applied

grasses of one kind tend to predominate and crowd out grasses of another kind. It has been found that the more highly pasture land is manured the simpler is the nature of its herbage (that is, the fewer are the different kinds of herbage growing on it). Unmanured pasture, on the other hand, is more complex in its herbage. The result is, that the application of manure to pasture land is attended with certain dangers. To maintain good pasture it is desirable to maintain a proper balance between the different kinds of grasses. For this reason permanent pasture may be said to be, of all crops, the least commonly manured. As a rule, it is only manured by the droppings of the cattle and sheep feeding upon it.

It is found that the influence of farmyard manure upon the composition of the pasture does not tend to the same extent to the undue development of one kind of grass over another; and in this respect it is probably to be preferred to artificial fertilisers. Sometimes, however, it is desirable to supplement farmyard manure with phosphates, in which case one of the best and justly esteemed phosphatic manures is bone dust, which may with great advantage be applied in autumn at the rate of from 4 to 5 cwt. per acre. Basic cinder is also a good manure.

The same reasons, however, do not hold with regard to rotation seeds, where an abundant growth is desired, and complexity of herbage is not so important. A further reason which exists for the manuring of meadow land is the greater impoverishment of the soil under such conditions. Nitrogenous fertilisers, more especially sulphate of ammonia, increase the proportion of the grasses proper, and diminish the proportion of the leguminous plants. The effect of farmyard manure,

while less marked in inducing simplicity of herbage, is similar to sulphate of ammonia. Potash manures, on the other hand, tend to develop leguminous plants in a herbage, so also do phosphates. Potash fertilisers, as a rule, are unnecessary, but in light or peaty soils they may be of service. Grass grown for hay may be manured with nitrate of soda in comparatively large quantities—viz., 2 to 3 cwt. per acre.

Of all crops, *roots* may be said to require the most liberal application of manure, and to respond most freely to it. They contain large quantities of three fertilising ingredients—nitrogen, phosphates, and potash—and may be regarded as exceedingly exhaustive crops. This is especially the case with mangolds, which make particularly large demands on a soil's fertilising ingredients.

Turnips are characterised by the large amount of sulphur they contain, and, according to some, this explains the beneficial effect which gypsum has when applied to them as a manure. This, however, is more probably to be explained by the indirect action of gypsum in setting free the potash of the soil. The fact that the successful cultivation of root crops depends on the application of large quantities of manure is recognised in practice, as they receive the most manure of any crop of the rotation. Roots flourish best on a light soil which is neither too wet nor too dry; but with liberal manuring and careful tillage they may be said to do well on any soil. Mangolds are generally more benefited by the application of nitrogenous fertilisers than are turnips or swedes, which, it would seem, have a greater power of absorbing nitrogen from the soil than the first-named crop; but it is a mistake to suppose

that any of the root crops are not dependent on a ready supply of nitrogen, and the fact that large crops of turnips can often be grown by the application of superphosphate alone may be taken as a proof that the soil contains plenty of nitrogen. Mangolds are, from their deeper roots, more capable of drawing their supply of phosphoric acid from the soil than turnips. They respond, therefore, as a rule, less freely than turnips or swedes to an application of superphosphate. Generally speaking, we may say that the characteristic manure for turnips is superphosphate; and that for mangolds is a nitrogenous manure, such as nitrate of soda or sulphate of ammonia.

A special reason for manuring root crops is the fact that they are more liable to disease than any other crops, and this is especially the case in the early stages of their growth. One of the great benefits conferred on the turnip crop by an application of superphosphate is the help it gives the crop to pass safely the critical stages of its growth. The superphosphate is best drilled in with the seed, in quantities varying from 3 to 5 cwt. In Scotland, it may be well to point out, the manure applied to this crop is very much in excess of the amount customarily applied in England; for in the former country large applications of manure may be profitably employed. Roots generally receive a large dressing of farmyard manure. Salt has been found in some districts to have a very good effect on the mangold crop, and potash is found to amply repay application.

Roots most commonly receive the bulk of the farmyard manure applied throughout the rotation. They may be regarded as the starting crop, and on them the most manure is expended, not merely on their own account,

but also on account of the crops that are to follow. In many respects they are well suited to be the recipients of this plant food. They are gross feeders, and distribute a very large amount of fibrous feeding rootlets in the soil. They are enabled, on this account, as well as on account of the long period of their growth—which extends for months—to avail themselves of the fertilising constituents supplied by the manure to a much greater extent than the cereals could do, and as they are generally fed off the land with sheep their manurial ingredients are thus returned to the soil.

Potatoes are often classed with the root crops, and in their manurial requirements they offer many points of similarity. Next to root crops, they may be said to make the most exhaustive demands on the soil, and therefore require a liberal general manuring. A point of importance in the manuring of potatoes is a good tilth in the soil, so as to enable a free expansion of the tubers to take place. Indeed, the mechanical condition of the soil is a consideration of first-rate importance in the growing of potatoes. They may be said to grow best on deep, warm soils; but, like roots, if liberally manured, they may be successfully grown on any soil. Farmyard manure has long been regarded as specially valuable for the potato crop. In many parts of Scotland it is applied in enormous quantities, ranging from 20 to 40 tons per acre. There can be little doubt that the value of farmyard manure, as well as other bulky manures, for the potato crop, is partly due to their mechanical influence on the soil. Potatoes are surface feeders, and require their food in a readily available condition. It is found desirable, therefore, to supplement farmyard manure by readily available artificial manures.

Potatoes repay the application of mixed manure containing all the fertilising ingredients better than most crops. The nitrogen is best applied in the form of nitrate of soda. Sulphate of ammonia does not seem, when farmyard manure is also applied, to have an equally valuable effect, as it influences the size of the tuber, producing an undue amount of small potatoes. When no farmyard manure is applied, however, sulphate of ammonia seems to have a good effect, especially in wet seasons.

With regard to the nature of the phosphatic manure to be applied, superphosphate is to be preferred. Potatoes make large demands on potash, and consequently require potassic manures. In consequence of the fact that they receive large applications of farmyard manure, the necessity for adding potash in the form of artificial manures does not generally exist. Potash, if applied in too large quantities, has been found to exert a deleterious effect.

The influence of the manure on the composition of the potato crop is of much interest. Potatoes grown without manure, just as in the case of roots, are found to have a larger percentage of nitrogen than potatoes grown with manure. The effect of manuring, therefore, is to increase the proportion of starch, which is the most important constituent of the potato. Mineral manures have a greater effect in increasing the percentage of starch than purely nitrogenous manures, but when used together a still greater increase is obtained than when used singly. Potatoes, like roots, are also much influenced by the season. The effect of season and manuring on the potato disease is worthy of notice. Wet seasons are favourable to the development of the disease.

It has been found that in a highly nitrogenous manured crop the proportion of diseased tubers is greater than in an unmanured crop.

In *leguminous crops*, which include clover, beans, peas, vetches, lucerne, etc., we have examples of crops not benefited by direct application of nitrogenous manures. They have the power of accumulating nitrogen in the surface soil in very large quantities, and are thus admirably suited for preceding in the rotation such crops as cereals, which benefit largely by nitrogenous manures, and which, from the fact of their being sold off the farm, are essentially exhausting. The value of alternating cereals with leguminous crops was, as we have already pointed out, recognised by the Romans. The best manure for them is farmyard manure. Phosphatic manures may often with advantage be applied, potash still more rarely.

In several respects the manurial requirements of *cabbages* are similar to those of turnips, though in other respects they differ. Cabbages are gross feeders, to which any kind of manure, applied in any quantity, does not come amiss. They must be liberally treated both with phosphates and with nitrogenous manures, since they remove from the soil a very large quantity of fertilising ingredients. Nitrate of soda in large quantities—as much as 4 cwt. per acre—may be applied with profit to them. The addition of salt to the nitrate of soda is highly to be recommended. This may be applied at the rate of 5 to 6 cwt. per acre. Potash is also a most effective manure; indeed, the amount of potash cabbages remove from the soil is very great. Farmyard manure may be applied in larger quantities to them with benefit than to any other crop.

The requirements of the *hop crop* in the matter of manures are rather singular, inasmuch as they require a slow-acting fertiliser. They are especially benefited by bulky nitrogenous manures such as shoddy, horn meal, hide scraps, hoofs, rape dust, &c.; and it is only when quick-acting manures are applied along with slow-acting manures that they will exercise their full influence. It is best to manure hops twice a year—in spring, with farmyard manure, supplemented by a slow-acting nitrogenous manure such as shoddy; and again in summer, with a more quick-acting manure. The dressings applied to hops are very large. As we have pointed out, the nature and amount of farmyard manure or artificial fertiliser applied to the different crops must be largely determined by the treatment of the crop preceding it in the rotation, and must not simply be determined by the crop itself.

QUESTIONS.

CHAPTER I.

1. What does chemical analysis teach us regarding the composition of plants?

2. What is the percentage of water in plants?

3. Does the amount of the mineral matter of plants vary?

4. Out of what elements is the organic matter composed, and in what percentage are they respectively present?

5. What are the chief chemical compound substances out of which plants are formed, and into what groups can you divide them?

6. What are some of the elements present in the ash?

7. What are the sources of plant food?

8. What elements do plants derive from the soil, and what from the air?

CHAPTER II.

9. What is meant by germination?

10. What are the conditions of germination?

11. What is meant by carbon assimilation, and under what conditions does it take place?

12. What are the sources of the carbonic acid gas present in the air?

13. Whence do plants derive the oxygen and hydrogen out of which a large portion of their tissue is formed?

14. In what forms do plants absorb their nitrogen?

15. How are these various forms of nitrogen converted into one another in the soil?

16. What is meant by ammonification and nitrification?

17. How do leguminous plants "fix" free nitrogen?

18. Why are nitrogen, phosphoric acid, and potash of special importance as fertilising constituents?

19. What are the chemical forms in which phosphoric acid and potash are present in the soil?

20. On what may the fertility of a soil be said to depend?

CHAPTER III.

21. How are virgin soils formed?

22. In what way, under agricultural practice, are the fertilising constituents of a soil removed?

23. Which crops are the most exhausting?

24. In what way do the fertilising constituents removed in crops from the soil find their way back again?

25. In what way does farmyard manure lose in value through careless management?

26. What is the nature of the losses which take place from a soil by drainage?

27. To what extent is nitrogen probably lost in this way?

28. Are there any natural processes whereby the soil gains in fertilising constitnents?

29. How may fertilisers be classified?

30. What is the difference between direct and indirect manures? Give examples.

CHAPTER IV.

31. Why should the composition of farmyard manure be variable?

32. Into what three classes may the constituents of farmyard manure be divided?

33. What substances, in addition to straw, are suitable for use as litter?

34. Why should the black liquor of farmyard manure be its most valuable constituent?

35. State approximately the amounts of nitrogen, phosphoric acid, and potash which farmyard manure, of average composition, may contain.

36. How are composts generally made?

37. How is sewage usually applied to land?

CHAPTER V.

38. What influence has guano had on the development of agricultural practice?

39. What is guano?

40. Where have the chief guano deposits been found?

41. Describe the properties of guano.

42. In what chemical conditions are its fertilising constituents present?

43. What is "rectified" guano?

44. State the percentages of nitrogen, phosphates, and potash in ordinary Peruvian guano.

45. What is fish guano? State the percentages of nitrogen and phosphates it usually contains.

46. What percentages of nitrogen and phosphates does meat guano contain?

CHAPTER VI.

47. Where is nitrate of soda obtained? To what does it owe its value as a fertiliser?

48. What is the composition of ordinary commercial nitrate of soda?

49. Why is nitrate of soda almost invariably applied as a top dressing?

50. Mention some of the benefits obtained from an application of nitrate of soda.

51. What is peculiarly characteristic of sulphate of ammonia as a nitrogenous manure?

52. Is the nitrogen in sulphate of ammonia as readily available as that in nitrate of soda?

53. What percentage of nitrogen does commercial sulphate of ammonia contain?

54. Mention the chief sources of sulphate of ammonia?

55. Under what conditions is nitrate of soda found to be a more economical nitrogenous manure than sulphate of ammonia?

56. State the percentage of nitrogen contained by dried blood.

57. Describe the action of dried blood when applied to the soil, and state what crops are benefited by its application.

58. On what soils does dried blood exert its maximum effect?

59. What is the percentage of nitrogen in horns and hoofs? Describe their action.

60. What is shoddy? What percentage of nitrogen does it contain?

61. To what constituent does soot owe its manurial value?

CHAPTER VII.

62. When were bones first used as manure in this country?

63. In what forms are bones usually applied?

64. State the percentages of phosphates and nitrogen bone meal and flour contain.

65. What are "dissolved bones," and in what respects do they differ from ordinary bones?

66. Describe the action of bones when applied to the soil.

67. What crop benefits most from the application of bones?

68. From what materials are "dissolved bone compounds" usually made?

69. What is bone-ash, and what percentage of phosphate of lime does it contain?

70. How is bone black obtained?

71. What is spent char?

CHAPTER VIII.

72. Describe the properties and composition of apatite.

73. What phosphates are most largely used in the manufacture of super-phosphates?

74. What are coprolites? What is their composition?

75. Have undissolved mineral phosphates any manurial value?

76. How is superphosphate obtained from mineral phosphates?

77. What is the composition of superphosphate of lime?

78. Explain the action of superphosphate when applied to the soil.

79. What is basic slag? What percentage of phosphate of lime does it contain?

80. What is peculiar about the chemical condition of phosphate in basic slag?

CHAPTER IX.

81. Why is there less necessity for potash manuring than for either nitrogenous or phosphatic manuring?

82. What soils are benefited by the application of potash?

83. Mention the chief potash fertilisers, with their percentages of potash.

84. What crops are most benefited by potash?

85. State the amount of fertilising constituents in seaweed.

CHAPTER X.

86. Explain the meaning of the term "indirect manure."

87. What soils are usually deficient in lime?

88. Why is the surface of pasture soils apt to be deficient in lime?

89. In what forms is lime used in agriculture?

90. Give an account of the mechanical action of lime in a soil.

91. What is the chemical action of lime when applied to the soil?

92. What effect has lime on the micro-organic life of the soil?

93. Explain the action of gypsum as a fertiliser.

94. What crops are benefited by the application of salt?

CHAPTER XI.

95. What value has chemical analysis in determining the value of a fertiliser?

96. What constituents of a fertiliser are tested for under the Fertilisers and Feeding Stuffs Act?

97. In what forms does nitrogen occur in different fertilisers? State these in their order of value.

98. What are the different forms of phosphates of lime in fertilisers?

99. Is the phosphate in a mineral phosphate, such as apatite, as valuable as that in bones?

100. What is meant by the unit value of a fertiliser, and how is it determined?

101. What means are adopted to effect the equal distribution of a fertiliser in the soil?

102. Mention the risks of loss which are apt to ensue on mixing manures.

103. How is sulphate of ammonia formed?

104. What is the result of mixing lime with an ammonia salt?

105. Is it safe to mix basic slag with sulphate of ammonia?

106. Why should nitrate of soda not be mixed with superphosphate?

107. What is meant by the reversion of soluble phosphate, and how is it caused?

108. Why should a quick-acting nitrogenous fertiliser not be mixed with a slow-acting phosphatic fertiliser?

CHAPTER XII.

109. Have fertilisers much influence on the permanent fertility of a soil?

110. What manure has the best influence on the permanent fertility of a soil, and why?

111. Name the fertilisers best applied in spring, and those best applied in autumn.

112. What fertilising ingredients are best applied to dry, light soils? What does a soil rich in organic matter usually require?

113. In a wet season whether is nitrate of soda or sulphate of ammonia the more economical manure?

114. Have bones any influence on the fertility of a soil after the first year of application?

115. What is the characteristic difference between the manurial requirements of cereals compared with other crops?

116. What class of manures have the best influence on cereals?

117. What kind of soil is most suitable for the growth of barley?

118. Mention the fertilisers, and the amounts usually applied to barley.

119. What fertiliser is usually applied to wheat?

120. Do roots respond to the application of slow-acting fertilisers?

121. What fertilising ingredient is usually required by oats?

122. Why is permanent pasture very seldom manured?

123. What is the safest manure to apply to permanent pasture?

124. Why are roots exhausting crops?

125. On what soils do roots grow best?

126. What is the characteristic manure for turnips and mangolds?

127. Why can roots avail themselves of the fertilising constituents applied much better than cereals?

128. The farmyard manure applied throughout the rotation is usually applied to the root crop. Why is this?

129. On what soils do potatoes grow best, and why are they usually classed with the roots?

130. What are the best nitrogenous and phosphatic fertilisers to apply to potatoes?

131. Describe the influence of fertilisers on the composition of potatoes.

132. What is the best manure to apply to leguminous crops?

133. Why should cabbages be liberally manured?

134. What fertilisers have the best effect on cabbages?

135. What is the best kind of manure for hops, and how often are they generally manured?

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